METALLOGENY OF THE VANCOUVER-HOPE AREA, BRITISH COLUMBIA

by

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ABSTRACT

The study area is characterized by complex terrane encompassing the junction of three major tectonic belts: the Coast Plutonic Belt, the Intermontane Belt, and the Cascade Belt. Examination of the detailed tectonic framework was facilitated by the construction of a time-space plot which illustrates the salient features of the six small-scale tectonic belts within the area. Subsequent examination of metal deposits was facilitated by the MINDEP inventory file which supplied location and reference information. Detailed descriptive information on metal deposits was categorized and tabulated with respect to metals, deposit type, host rock formation and host rock type. This data was then integrated into the tectonic framework to outline a metallogenic model for the area.

A simplistic model for the evolution of the major features in the area involves eugeosynclinal and trench-like deposition from Upper Paleozoic until Jurassic-Cretaceous time when the developing Coast volcanic and plutonic arc collided with the established Intermontane arc on the east. Arc volcanism in the Coast Plutonic Belt produced the initial volcanogenic metal sulfide accumulations in the area which subsequently were remobilized into adjacent areas during collision. The axis of collision contains a major magmatic sulfide deposit which probably formed at this time as a result of collision. Significant mineralization is found also west of the collision axis near the deep-seated Hozameen fault along which gold-rich fluids have formed veins near serpentine bodies. Similarly, a large disseminated gold deposit occurs in slate adjacent to the Hozameen fault in the area of major vein mineralization.

Subduction responsible for the Tertiary episode of plutonism and volcanism centered in the Cascade Belt also produced small skarn, vein and

porphyry deposits during a subsequent episode of remobilization mineralization.

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1. INTRODUCTION

GENERAL STATEMENT

The objective of this study is to define the metallogenic history of the southern end of the Coast Plutonic Belt and adjacent areas which include the northern tip of the Cascade Belt and a small portion of the southwestern edge of the Intermontane Belt (Figure 1-1). Each of these major tectonic belts is characterized by distinctive geological features, but location of boundaries between belts is difficult on the detailed scale of this study.

Metallogenesis is approached from two viewpoints, firstly through description of important individual deposits and groups of deposits, and secondly through statistical compilations of specific characteristics determined for every deposit for which published descriptive information is available. The second approach enables deposits of all sizes to be considered in order to obtain a more detailed view of metal distributions, and is based on the hypothesis that small occurrences should not be ignored in an area where large deposits are rare. Both these sections are preceded by a detailed examination of the geology and tectonic environment, presented on a geologic map, cross-section and time-space plot (in pocket). The nature of the time-space plot will be discussed in detail in Chapter Two.

A similar study of the adjoining Taseko Lakes-Pemberton area to the north (Woodsworth, et al., 1977) suggested that abundant vein deposits along the eastern edge of the Coast Plutonic Complex were formed by fluids which might have originated in plutonic rocks during cooling. However, such patterns are not readily apparent in the area considered here.

Of secondary importance to this study is the evaluation of the MINDEP system as a quantitative approach to metallogenic studies. Details regarding the MINDEP system are discussed in Chapter Four.

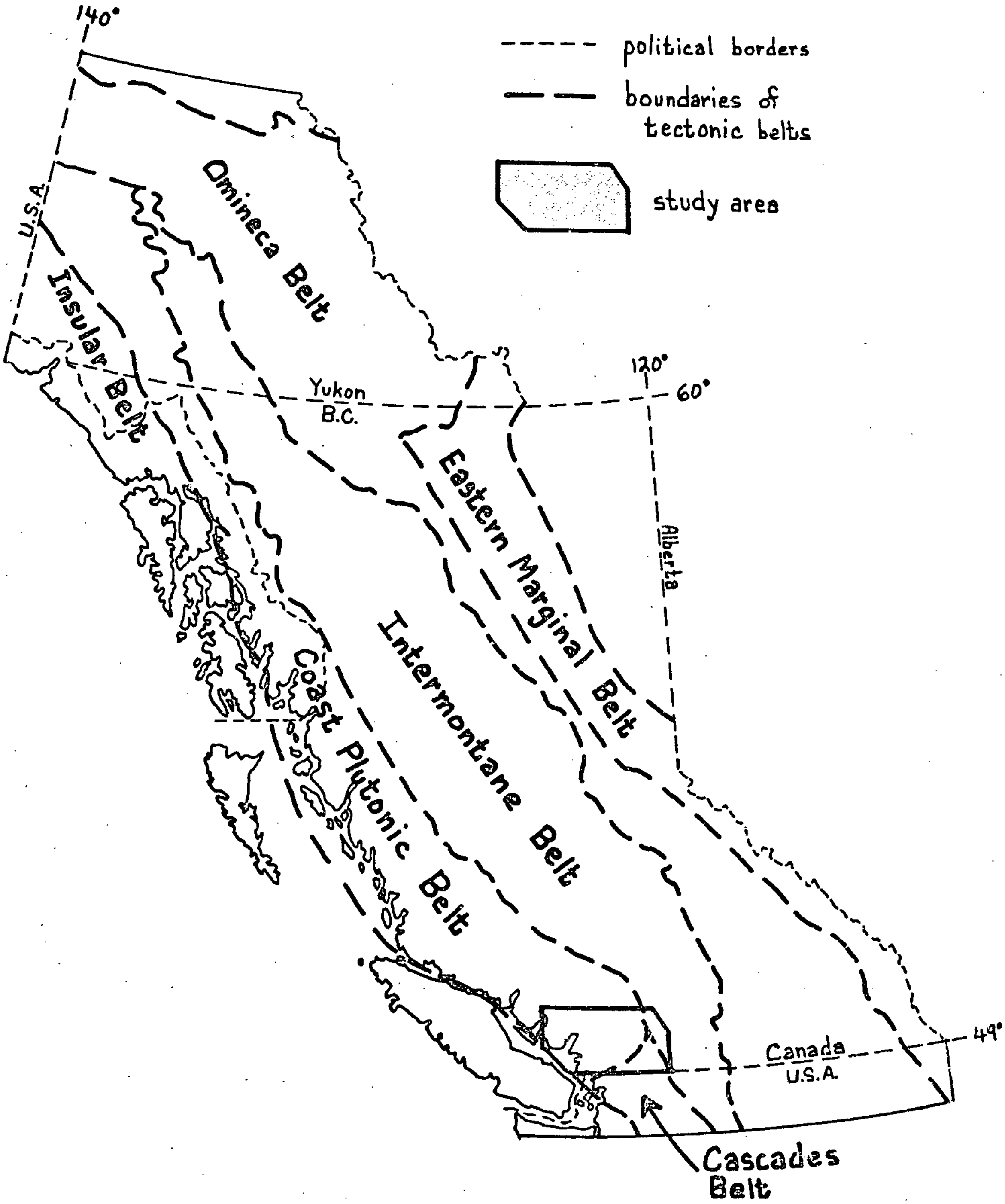

Figure 1-1. Location of the study area relative to the tectonic belts of the Canadian Cordillera (after Sutherland Brown, et al., 1976).

DEFINITION OF THE STUDY AREA

The boundaries of the study area enclose approximately 28,711 square kilometers, 18 percent covered by water and recent sediments. The original boundaries at the outset of the study were contained within NTS sheets 92-G and 92-H, West Half, but were subsequently modified for three reasons (refer to Figure 1-2 for definition of NTS boundaries):

1) The northern boundary was extended to include the cluster of deposits southwest of Pemberton. One of these deposits, Northair, is the only currently producing deposit in the study area.

2) The southern portion of the eastern boundary was extended to include an area which contains few metal deposits, but whose geology is valuable to an understanding of the tectonic history of the area.

3) The entire eastern boundary was modified to extend only so far as the main area of outcrop of the Nicola and Kingsvale Groups. The Nicola Group contains a large number of metal deposits which probably are not related to the Coast Plutonic Complex.

METHODS

Descriptive information on metal deposits was gathered through an extensive literature search. Principal sources of information include the Annual Reports of the British Columbia Minister of Mines, Geology, Exploration and Mining in British Columbia, and Assessment Reports for the Vancouver and New Westminister Mining Districts. A few private company reports were made available to the author. Field investigations in the summer of 1975 served to familiarize the author with some of the deposits.

Data were transferred onto coding forms and entered into the MINDEP data bank for storage and later retrieval. Raw data output from this data bank was an invaluable tool to the compilation process.

Deposits are identified with reference to the NTS sheet in which they occur. Since all sheets in the study area are within the 92 grid, this number has been dropped. Therefore, the identification number of a deposit in the 92-H sheet, southwest quarter, will be preceded by the letters HSW. Figure 1-2 locates deposits in the study area and the grids in which they occur.

2. GEOLOGY AND TECTONIC FRAMEWORK

INTRODUCTION

Figure 1-1 illustrates the position of the present study area relative to the six major sub-parallel belts of the Canadian Cordillera (Sutherland Brown, et al., 1976).

The general geology of the area, shown in Figure 2-1 (see also Tables 2-1 and 2-2), has been compiled from numerous sources (viz., Bostock, 1963; Roddick, 1965; Monger, 1970; Rice, 1960; Woodsworth, 1977; Roddick and Hutchison, 1973; Duffel and McTaggart, 1952; Richards and McTaggart, 1976; and Roddick and Okulitch, 1973). Two-thirds of the area is underlain by intrusive rocks, most belonging to the Coast Plutonic Complex; sedimentary rocks dominate the southeastern section and occur with volcanic rocks in scattered remnants throughout the Coast Plutonic Belt. A transition zone between western plutonic and eastern sedimentary terranes is characterized by metamorphic rocks of unknown age which merge into the structurally complex Cascades region to the south. Transecting the study area are the north-south-trending Fraser River Fault Zone[1] and three other faults believed to have major horizontal and/or vertical components.

The author has divided the study area further into six tectonic sub-divisions, which, from east to west, are the Eagle Plutonic Belt, the Ladner Trough, the Hozameen Basin, the Cascade Belt, the Spuzzum Plutonic Belt and the Coast Plutonic Belt. The Cascade Belt, due to its complexity, has been subdivided further into four belts, referred to as C-1, C-2, C-3 and C-4.

The time-space plot (Figure 2-2; described below) has used these tectonic divisions to present data not evident on the geologic map (Figure

[1] also referred to herein as the Straight Creek Fault Zone

TABLE 2-1. Abbreviations used to identify units on the Geologic Map (Figure 2-1). Units are arranged alphabetically within tectonic belts; see text for descriptions and ages.

I. Eagle Plutonic Belt

CQ	Coquihalla Group
N	Nicola Group

II. Ladner Trough

CQ	Coquihalla Group
CR	Coast Plutonic Complex
DC	Dewdney Creek Group
JM	Jackass Mountain Group
L	Ladner Group
P	Pasayten Group

III. Hozameen Basin

CR	Coast Plutonic Complex
HZ	Hozameen Group
Qs	Quaternary sediments

IV. Cascade Belt

C	Cultus Formation
CH	Chilliwack Group
CK	Chuckanut Formation
CR	Coast Plutonic Complex
D	Darrington Phyllite
NK	Nooksack Group
Qs	Quaternary sediments
SK	Skagit Formation
YA	Yellow Aster Crystalline Complex

V. Spuzzum Plutonic Belt

av	acid volcanic rocks
CR	Coast Plutonic Complex
gn	gneiss
ms	metasedimentary rocks
Qs	Quaternary sediments
SS	Settler Schist

VI. Coast Plutonic Belt

AP	Agassiz Prairie Formation
av	acid volcanic rocks
BH	Brokenback Hill Formation
BI	Bowen Island Group
BME	Billhook Creek Formation Mysterious Creek Formation Echo Island Formation
bv	basic volcanic rocks
CEH	Cheakamus Formation Empetrum Formation Helm Formation
CR	Coast Plutonic Complex
FL	Fire Lake Group
G	Gambier Group
GB	Garibaldi Group
gn	gneiss
HL	Harrison Lake Formation
K	Kent Formation
m	metamorphic rocks
ms	metasedimentary rocks
PI	Pioneer Formation
PN	Peninsula Formation
Qs	Quaternary sediments
s	sedimentary rocks
TI	Twin Islands Group

TABLE 2-2. Brief descriptions of units outside the study area which are shown on the Geologic Map (Figure 2-1) but not discussed in the text. Where possible, information was updated from Roddick and Okulitch, (1973).

Symbol	Name	Description	Age	Reference
abv		plateau basalt and dacite flows; may be equivalent to Garibaldi Group	late Miocene or Pliocene	Roddick and Hutchison, 1973
bv-1		andesite; minor amounts of dacite	lower Tertiary	Roddick and Hutchison, 1973
bv-2		valley and plateau basalt	late or post-Miocene	Rice, 1960
CW	Coldwater Beds	sandstone, shale, conglomerate; coal seams	Eocene	Duffel and McTaggart, 1952
HU	Hurley Formation	argillite, limestone, tuff, conglomerate, andesite flows	Upper Triassic	Roddick and Hutchison, 1973
KL	Kamloops Group	basalt and dacite	Eocene and Oligocene	Duffel and McTaggart, 1952
KVs	Kingsvale Group; sedimentary rocks	arkose, conglomerate, greywacke	Upper Cretaceous	Rice, 1960
KVv	Kingsvale Group; volcanic rocks	basalt and andesite lavas; agglomerate, tuff, breccia	Upper Cretaceous	Rice, 1960
PRs	Princeton Group; sedimentary rocks	basin conglomerate, sandstone and shale	Eocene	Rice, 1960
PRv	Princeton Group; volcanic rocks	basalt, andesite and dacite lavas	Eocene	Rice, 1960
s,bv		sedimentary and volcanic rocks	mid-Eocene	Duffel and McTaggart, 1952
SB	Spences Bridge Group	andesite and dacite lava and pyroclastic rocks; minor amounts of basalt and rhyolite	Lower Cretaceous	Rice, 1960

2-1). Both the geologic map and the time-space plot should be constantly referred to as illustrations of events and relationships discussed throughout the text.

TIME-SPACE PLOT

The time-space plot (Figure 2-2) is designed to diagrammatically illustrate events occurring in a particular area at a particular time in order to clarify cause/effect relationships which are difficult to portray on geologic maps or cross-sections.[2] Events represented on the plot include:

1) Deposition

2) Intrusion (K/Ar dates are plotted as minimum ages; location and source of these dates are shown in Figures 2-3a,b and Table 2-3)

3) Faulting (fault movement is depicted along corresponding belt divisions or in the affected belt in an approximate east-west position according to units affected)

4) Folding (without significant metamorphism)

5) Deformation (period of folding, faulting and metamorphism which generally masks the original character of rocks)

A vertical time axis is presented to scale (except where noted) and is divided according to Van Eysinga, 1975. The horizontal distance axis consists of two schematic northeast-southwest transects offset in a north-south direction between the Spuzzum Plutonic Belt and the Cascade Belt. Distance is not to scale in order to accommodate events in the very narrow belts.

Important aspects which cannot be portrayed on a time-space plot include the following:

1) True stratigraphic thicknesses are not shown in order to illustrate the actual or possible duration of deposition or formation of a unit.

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[2] Griffiths (1977) discusses the construction and application of time-space plots in detail.

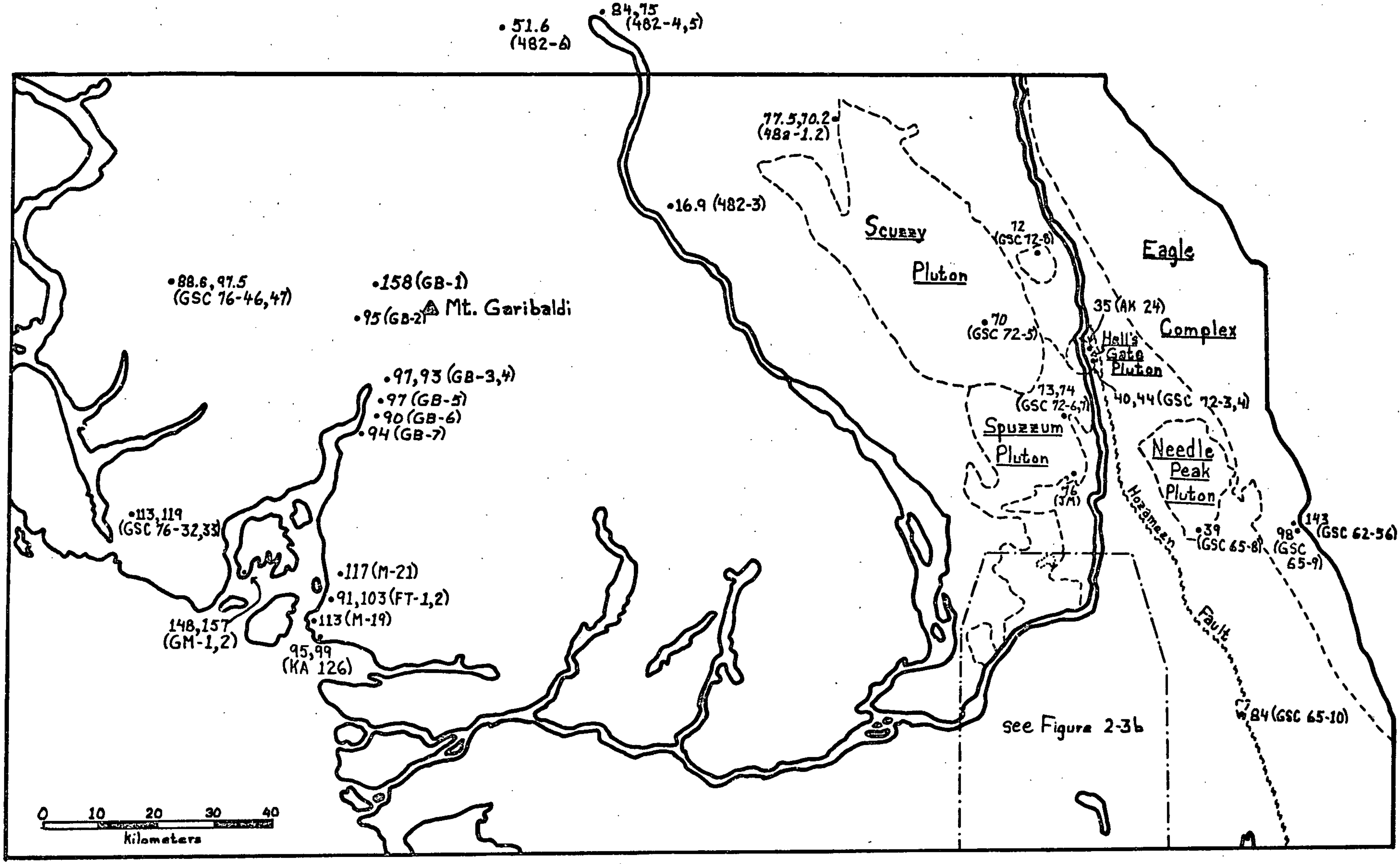

Figure 2-3a. Location of K/Ar radiometric determinations on plutonic rocks in and near the study area. Refer to Table 2-3 for brief sample descriptions and sources of information.

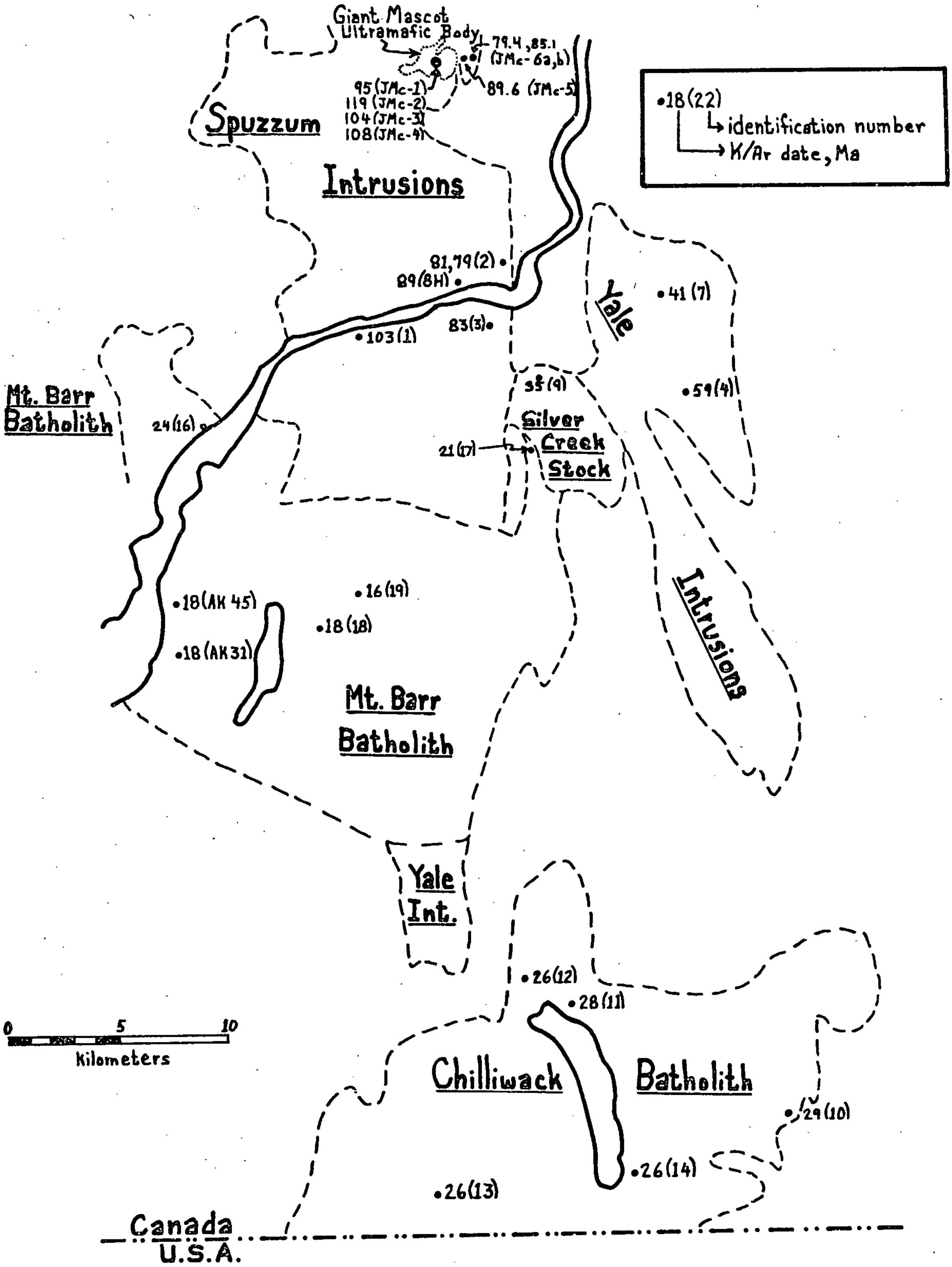

Figure 2-3b. Location of K/Ar radiometric determinations from intrusive rocks in a portion of the study area (after Richards and McTaggart, 1976, and McLeod, et al., 1976).

TABLE 2-3. K/Ar RADIOMETRIC DETERMINATIONS ON PLUTONIC ROCKS IN AND NEAR THE STUDY AREA; SEE FIGURE 2-3a,b FOR LOCATIONS.

Identification Number	Pluton(s)	Rock Type	Material Analysed	Age (Ma)	Reference
GSC 62-56	Eagle Complex	Granodiorite	Biotite	143	Leech, *et al.*, 1963
GSC 65-8	Needle Peak	Granite	Biotite	39 ± 4	Wanless, *et al.*, 1967
GSC 65-9	Eagle Complex	Granodiorite	Biotite	98 ± 6	"
GSC 65-10	pluton on Hozameen Fault	Granodiorite	Biotite	84 ± 6	"
GSC 72-3	Hell's Gate	Quartz Diorite	Hornblende	40 ± 4	Wanless, *et al.*, 1973
GSC 72-4	Hell's Gate	Quartz Diorite	Biotite	44 ± 3	"
GSC 72-5	Scuzzy	Quartz Diorite	Biotite	70 ± 4	"
GSC 72-6	Spuzzum	Quartz Diorite	Hornblende	73 ± 4	"
GSC 72-7	Spuzzum	Quartz Diorite	Biotite	74 ± 4	"
GSC 72-8	Scuzzy	Quartz Diorite	Hornblende	72 ± 4	"
GSC 76-32	Coast Plutonic Complex	Granodiorite	Biotite	113 ± 4	Wanless, *et al.*, 1977
GSC 76-33	Coast Plutonic Complex	Granodiorite	Hornblende	119 ± 5	"
GSC 76-46	Coast Plutonic Complex	Granodiorite	Biotite	88.6 ± 3.3	"
GSC 76-47	Coast Plutonic Complex	Granodiorite	Hornblende	97.5 ± 4.5	"
KA 126	Coast Plutonic Complex	Granodiorite	Biotite	99,95	Baadsgaard, *et al.*, 1961
AK 24	Hell's Gate	Granodiorite	Biotite	35	"
AK 31	Mt. Barr	Quartz Diorite	Biotite	18	"
AK 45	Mt. Barr	Quartz Diorite	Biotite	18	"
1a	Spuzzum	Quartz Diorite	Biotite	103 ± 5	Richards and White, 1970
1b	Spuzzum	Quartz Diorite	Biotite	103 ± 5	"
2a	Spuzzum	Quartz Diorite	Biotite	79 ± 4	"
2b	Spuzzum	Quartz Diorite	Hornblende	81 ± 4	"
3	Spuzzum	Quartz Diorite	Biotite	83 ± 4	Richards and McTaggart, 1976
4a	Yale	Granodiorite	Biotite	59 ± 3	Richards and White, 1970
4b	Yale	Granodiorite	Biotite	59 ± 3	"
7	Yale[1]	Quartz Monzonite	Biotite	41 ± 2	"
9	Silver Creek Stock	Quartz Diorite	Hornblende	35 ± 2	"
10	Chilliwack	Gabbro	Biotite	29 ± 1	"
11	Chilliwack	Quartz Diorite	Biotite	28 ± 1	"
12	Chilliwack	Quartz Monzonite	Biotite	26 ± 1	"
13	Chilliwack	Quartz Monzonite	Biotite	26 ± 1	"
14	Chilliwack	Quartz Monzonite	Biotite	26 ± 1	"
16a	Mt. Barr	Quartz Diorite	Biotite	24 ± 1	"
16b	Mt. Barr	Quartz Diorite	Biotite	24 ± 1	"
17	Mt. Barr	Granodiorite[1]	Biotite	21 ± 1	"
18	Mt. Barr	Quartz Diorite[1]	Biotite	18 ± 1	"
19	Mt. Barr	Quartz Monzonite	Biotite	16 ± 1	"
8H	Spuzzum	Diorite	Hornblende	89 ± 2.8	Richards and McTaggart, 1976
JMc 1	Giant Mascot Ultramafite	Hornblendite	Hornblende	95 ± 4	McLeod, *et al.*, 1976
JMc 2	Giant Mascot Ultramafite	Hornblende Pyroxenite	whole rock	119 ± 4	"
JMc 3	Giant Mascot Ultramafite	Hornblendite	Hornblende	104 ± 4	"
JMc 4	Giant Mascot Ultramafite	Hornblendite	Hornblende	108 ± 4	"
JMc 5	Spuzzum	Diorite	Hornblende and pyroxene	89.6 ± 3.1	"
JMc 6a	Spuzzum	Tonalite	Biotite	79.4 ± 2.5	"
JMc 6b	Spuzzum	Tonalite	Hornblende	85.1 ± 2.8	"
JM	Spuzzum			76	Monger, 1970
482-1	Coast Plutonic Complex	Quartz Diorite	Hornblende	77.5	Woodsworth, 1977
482-2	Coast Plutonic Complex	Quartz Diorite	Biotite	70.2	"
482-3	Coast Plutonic Complex	Granodiorite	Hornblende	16.9	"
482-4	Coast Plutonic Complex	Granodiorite	Biotite	84	"
482-5	Coast Plutonic Complex	Granodiorite	Hornblende	75	"
482-6	Coast Plutonic Complex	Diorite	Hornblende	51.6	"
GB-1	Coast Plutonic Complex		Biotite	158	White, 1968
GB-2	Coast Plutonic Complex		Biotite	95	"
GB-3	Coast Plutonic Complex		Hornblende	97	"
GB-4	Coast Plutonic Complex		Biotite	93	"
GB-5	Coast Plutonic Complex		Amphibole	97	"
GB-6	Coast Plutonic Complex		Biotite	90	"
GB-7	Coast Plutonic Complex	Granodiorite	Biotite	94	Mathews, 1968
GM-1	Coast Plutonic Complex	Quartz Diorite	Hornblende	148 ± 5	McKillop, 1973
GM-2	Coast Plutonic Complex	Quartz Diorite	Biotite	157 ± 5	"
M-19	Coast Plutonic Complex	Diorite	Hornblende	117 ± 4	Caron, 1974
M-21	Coast Plutonic Complex	Granodiorite	Biotite	113 ± 3	"
FT-1	Coast Plutonic Complex		whole rock	91	Roddick, *et al.*, 1977
FT-2	Coast Plutonic Complex		Hornblende	103	"

[1] description revised by Richards and McTaggart, 1976

2) Displacements along major faults cannot be shown, but time and place of major faulting and units affected by faulting are shown. Major horizontal movement might have juxtaposed units that originally were not side-by-side.

3) Relationships between units which are not conformable are not represented. Gaps between units in the same structural belt might represent disconformities, angular unconformities, or the units might not be in contact with each other, but but spatially separated within the same belt.

EAGLE PLUTONIC BELT

Units Within the Eagle Plutonic Belt

Schistose basic volcanic rocks of the Nicola Group (N), granodiorite, tonalite and gneiss of the Eagle Complex, and acid extrusions of the Coquihalla Group (CQ) are the main lithologic units in the Eagle Plutonic Belt. Of these three units, the Eagle Complex is by far the most widespread.

Nicola greenstones are part of a large area of diverse submarine flows, flow breccias and shaley to limy sedimentary rocks east of the study area, but they occur intermittently in the study area only within and around the borders of the Eagle Complex. Fossils in the Nicola Group outside the study area are Upper Triassic (Rice, 1960).

Coarse-grained, northwesterly-foliated granodiorite and tonalite (apparently of intrusive origin) make up the majority of the Eagle Complex, but pegmatite, gneiss and migmatite are common. Age constraints place intrusion between extrusion of Late Triassic Nicola Group, which is intruded and metamorphosed by the Eagle Complex (Cairnes, 1924),[3] and deposition of Albian (uppermost Lower Cretaceous) Jackass Mountain conglomerates to the west, which contain cobbles of Eagle (?) granodiorite (Coates, 1974). Two samples of foliated granodiorite along the Hope-Princeton highway have

[3] An alternate hypothesis is that of Anderson (1971), who believes intrusive rocks of the Eagle Complex were derived from the Nicola Group by anatectic melting. Metamorphic effects spatially associated with the Eagle/Nicola contact are interpreted by Anderson as effects of thermal gradients responsible for the formation of the Eagle Complex, not products of intrusion.

yielded K/Ar model ages of 148 Ma (Leech, et al., 1963) and 98 Ma (Wanless, et al., 1967).

Subaerial Coquihalla volcanic rocks were deposited on an uplifted and eroded surface of granodiorite (Cairnes, 1924), and onto sedimentary rocks west of the granodiorite, thereby covering the fault which forms the western boundary of the Eagle Plutonic Belt. R. G. Berman (personal communication, 1978) recognizes a 4,000-foot section of rhyolitic flows and pyroclastic rocks intruded by andesitic to dacitic bodies. These stratified volcanic rocks are intruded by a massive dioritic plug which is probably a late intrusive phase of the Coquihalla Group (Cairnes, 1924). Extrusion of the Coquihalla Group is bracketed by three K/Ar determinations on dacite/andesite, rhyolite and diorite which yielded dates of 19.5 $\pm$ 0.9, 20.9 $\pm$ 0.7, and 22.1 $\pm$ 0.8 Ma, respectively (R. G. Berman, personal communication, 1978).

Deformation

Monger (1970) states that the Eagle Complex, although foliated, was not affected by major mid-Cretaceous compressive deformation evident in rocks farther west. However, mid-Cretaceous uplift of the Eagle Complex did occur along the Pasayten Fault. Large faults and folds in the Eagle Complex were not recognized by Staatz, et al., (1971) in studies south of the border; they concluded that mid-Cretaceous deformation did not extend east of the Pasayten Fault.

On the other hand, Anderson (1971) described folded metasedimentary gneisses of the Eagle Complex which have "undergone the same deformational event" as rocks west of the Pasayten Fault, while more competent tonalite does not exhibit folding. The 98 Ma date (Wanless, et al., 1967) is also a contradiction to the supposed lack of mid-Cretaceous deformation. However, if the Eagle Complex was unroofed and supplying sediment to a westerly basin in Albian time (108-100 Ma), the significance of the 98 Ma radiometric date is not clear.

If Monger and Staatz, et al., were familiar only with granodiorite and tonalite of the Eagle Complex, deformation recognized by Anderson has yet to be examined adequately. Certainly the contradictions are indicative of a poor understanding of the character and history of the Eagle Complex.

Pasayten Fault

Considerable vertical and right-lateral movement is assumed to have occurred along the steep westerly-dipping Pasayten Fault which forms the western boundary of the Eagle Plutonic Belt (Coates, 1974). Movement along the fault produced cataclastic textures and increased intensity of foliation near the fault in rocks of the Eagle Complex. Small, unfoliated plugs near the fault have been dated at 94 Ma (Staatz, et al., 1971). On the assumption that these plugs, if present, would have been affected by movement of the Pasayten Fault, Staatz, et al., placed an upper limit of 94 Ma on fault movement. Rocks east of the Pasayten Fault are believed by Coates (1974) to be the source of Lower Cretaceous arkosic sediments in the trough west of the fault, thus fault movement could have occurred as early as lowermost Cretaceous.

LADNER TROUGH

The fault-bounded Ladner Trough records a long history of sedimentation which is important in determining the timing of uplift of adjacent areas. Detailed studies by Coates (1974) provide most of the data discussed below.

Stratigraphic Units

Fossil evidence indicates that deposition of the slaty Jurassic Ladner Group (L) might have begun as early as Sinemurian, and continued through mid-Bajocian. Deposition occurred along a basin which was open to the west and receiving sediment from an easterly volcanic highland (probably Nicola). Sediments forming the eastern and western portions of the basin represent two different environments of sedimentation: eastern shallow-water to subaerial, coarse-grained volcanic sediments with minor amounts of fine-grained marine turbidites and andesitic flows contrast with western deep-water pelagic sediments and turbidites. Easterly-derived arkosic sandstones toward the top of the western sequence indicate shallowing in Bajocian time.

The Upper Jurassic Dewdney Creek Group (DC) lies disconformably or with slight angular unconformity above the western part of the Ladner Group. Shallow-water marine sediments consisting of volcanic sandstone and sandy argillite were derived from an easterly volcanic source. Minor amounts of granitic detritus appear in conglomerates near the base of the sequence.

Minor alluvial sedimentation and volcanism was reported by Coates to have occurred between deposition of Dewdney Creek and Jackass Mountain Groups, but due to factors such as rare and indeterminate fossils, faulted contacts, and the restricted extent of these units, they are not discussed further.

Mixed marine and non-marine conglomerates and sandstones (Hauterivian to mid-Albian) of the Jackass Mountain Group (JM) lie disconformably above the Dewdney Creek Group. The northern section is described by Monger (1970) as dark, massive greywacke and interbedded conglomerate which may be partly non-marine. Coates described the southern sections as shallow marine sandstones and conglomerates with local stagnant and non-marine portions. Throughout most of the sequence an easterly source is indicated by increasing grain size toward the east. In addition, recognizeable detritus from Eagle and Nicola terranes was noted by Coates. Conglomerates record a sudden uplift to the east in early Albian time (i.e., movement along the Pasayten Fault); westerly-derived sediments become evident near the top of the

Jackass Mountain Group.

Non-marine Aptian-Albian Pasayten Group (P) conglomerate, sandstone and pelite overlie and interfinger with dominantly marine Jackass Mountain Group rocks to the east. A sudden change to a high energy environment occurred in Albian time, recorded by deposition of red beds, poorly sorted conglomerates and fanglomerates. Coates believed Albian sediments indicate both a westerly volcanic-sedimentary provenance and an easterly plutonic-metamorphic provenance; increasing proportions of westerly-derived sediments occur toward the top of the section.

Other units of minor importance in the Ladner Trough are volcanic rocks of the Coquihalla Group, Needle Peak pluton, and a small region of Nicola (?) volcanic rocks (Figure 2-1) along the Pasayten Fault. The southern area designated as Coquihalla volcanic rocks is not correlated definitely with the Coquihalla Group; it unconformably overlies Lower Cretaceous sedimentary rocks and the Chuwanten Fault (see below), suggesting a Tertiary age. Needle Peak pluton is a discordant intrusion of coarse granite and granodiorite which has been dated at 39 Ma (Wanless, *et al.*, 1967). Not much is known of the small area of rocks which Rice (1960) mapped as Nicola Group, as he does not describe the occurrence in detail. It is possible that this occurrence does not belong to the Nicola Group, as it is on the western ("wrong") side of the Pasayten Fault, but it remains as Nicola in this study for lack of contrary evidence.

Metamorphism of rocks of the Ladner Trough is slight, being confined to zeolite or lowermost greenschist facies.

Deformation

The Chuwanten Fault is an imbricate southwesterly-dipping thrust zone which probably is related genetically to major flexural-slip folding during Late Cretaceous compression. South of the border, Tabor, *et al.*, (1968) report an 86 Ma dike offset by the Chuwanten Fault, indicating initiation or renewal of movement after this time. Folding, however, may have begun as early as Cenomanian, as the Upper Albian Pasayten and Jackass Mountain Groups are the youngest units involved. An upper limit for both folding and faulting is uncertain, but placed as lowermost Tertiary, since the Straight Creek Fault Zone truncates deformed Albian sedimentary rocks. A real upper limit is defined by the Eocene Needle Peak pluton which clearly post-dates major structures.[4]

Hozameen Fault

Just as the Pasayten Fault forms the eastern edge of the Ladner Trough, so the western edge is defined by the Hozameen Fault. A major crustal break with probably mantle-derived, tectonically-emplaced serpentine (Misch, 1966) along its trace, exposures of the Hozameen Fault are vertical to steeply westerly-dipping over thousands of vertical feet in some places (Staatz, et al., 1971), but flatten south of the United States-Canada border to blend with the easterly-directed Jack Mountain Thrust Prong (cf. Figure 2-4). Considerable vertical movement is presumed to have occurred, with the west side moving up relative to the east side.

Movement along the Hozameen Fault is related to major mid- to Late Cretaceous deformation involving Ladner Trough sedimentary rocks. Timing of the onset of movement is not known, but is probably recorded by westerly-derived, high-energy Pasayten sediments in Albian time. An 84 Ma pluton on the trace of the fault (Coates, in Wanless, et al., 1967) gives an upper limit to fault movement.

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[4]The upper limit proposed by Coates is 84 Ma, the age of a small pluton that intrudes Ladner slates along the western boundary of the area. Although this pluton might clearly post-date structures here, it does not necessarily post-date structures in the rest of the belt, and it contradicts the evidence for later (post-86 Ma) movement along the Chuwanten Fault.

This upper limit for the Hozameen Fault roughly coincides with the onset of movement along the Chuwanten Fault, perhaps indicating that easterly-directed compression (with consequent deformation and thrusting) was a pattern that persisted throughout Upper Cretaceous time, but the locus of thrusting shifted to the east in mid-Upper Cretaceous.

The Hozameen Fault is truncated to the north along the Fraser River where the Straight Creek and Fraser River Fault Zones merge to form the eastern boundary of the Ladner Trough. The Straight Creek Fault, discussed in detail below, is an important feature of the Cascade Belt.

HOZAMEEN BASIN

Hozameen Group

The Hozameen Group (HZ) was formed in an oceanic basin in which chert, volcanic rocks, and limestone were deposited along with fine pelitic rocks. Ribboned chert, generally associated with pelite, is abundant. Limestone lenses are rare, and most commonly are associated with basaltic, locally pillowed greenstone. A paleogeographic reconstruction depicts a deep marine basin with volcanic islands and associated atolls (Monger, 1977).

Absence of fossils, and contacts which are either tectonic or with Upper Cretaceous or younger units or with metamorphic units, have obscured the age of the Hozameen Group. A Pennsylvanian-Permian age has been assigned tentatively based on lithologic similarities with the Cache Creek Group (Monger, 1970); Lower to Middle Triassic has also been assigned on similar grounds with the Fergusson Group (Cameron and Monger, 1971).

Lowermost greenschist facies regional metamorphism affected most of the Hozameen Group; metamorphic grade increases toward the western contact where almandine amphibolite grade rocks of the Hozameen Group appear to blend with the Custer Gneiss unit of that grade.

Yale Intrusions

The foliated stocks, sills and dikes which intrude the western edge of the Hozameen Group are referred to as the Yale intrusions (McTaggart and Thompson, 1967). Rock types vary considerably, but biotite granodiorite is most common. All types exhibit some degree of cataclasis, with sheared, mylonitized and gneissic varieties common. Planar structures in intrusions parallel those in adjacent country rocks. The Paleocene to Eocene age of the Yale intrusions is based on inclusions of Settler Schist, Hozameen Group, Custer Gneiss and Spuzzum intrusions, intrusion by the Chilliwack Batholith, and radiometric dates of 59 and 41 Ma (Richards and McTaggart, 1976).

Deformation

Deformational history of the Hozameen Basin is summarized as follows:

1) Pre-Jurassic development of northwesterly-trending folds and faults (McTaggart and Thompson, 1967; Monger, 1970).

2) Minor northeasterly-trending folding and deformation associated with uplift along the Hozameen Fault during mid-Cretaceous.

3) Northwesterly folding in the southern portion related to Late Cretaceous Ladner Trough deformation (Monger, 1970).

4) Eocene shearing of the Yale intrusions, probably synchronous with major faulting along the Fraser River and Straight Creek Fault Zones (McTaggart and Thompson, 1967). Folding associated with these fault zones is of local significance, and therefore not represented on the time-space plot.

Boundaries

The western boundary of the Hozameen Basin is defined by the gradational metamorphic contact between Hozameen Group greenstones and amphibolite facies Custer Gneiss in the southern and central portions, and by the Straight Creek Fault Zone in the northernmost portion of the area. Neither the Hozameen Group nor the Yale intrusions occur west of these boundaries; both are clearly truncated in the Straight Creek Fault Zone by the Straight Creek and Hope Faults.

CASCADE BELT

A simplified view of Cascade structure is that of a metamorphic core overlain by folded and faulted sedimentary rocks. The core was uplifted along a north-south axis, uplift increasing northward. Both core and flanking sedimentary rocks were intruded by Tertiary plutons and overlain by Tertiary volcanic rocks. All of these elements which Misch (1966) described in detail for rocks south of the border, are present in the study area. Information in this section is from Misch's 1966 report, except where noted; Figure 2-4 illustrates the geology referred to south of the border.

In a recent summary of Northern Cascades geology, Misch (1977) outlines three belts divided by the Straight Creek and Ross Lake (Hozameen) Faults; these belts represent fault-bounded crystalline core flanked by easterly and westerly sedimentary belts. These divisions are retained in this study, but further subdivisions are also made.

Misch's eastern sedimentary belt ("East of the Hozameen Fault") has already been discussed as the Ladner Trough and Hozameen Basin which are clearly separated by the Hozameen Fault in the study area. South of the area (Figure 2-4) the continuation of the Hozameen Fault is the Jack Mountain Prong, a shallow, easterly-directed thrust whose upper plate contains the Hozameen Group. The western contact of the Hozameen Group south of the area is defined by the Jack Mountain Prong, but in the study area it is gradational into the Custer Gneiss; Tertiary intrusions and volcanism have obliterated the connection between these features across the border.

The central "East of the Straight Creek Fault" belt of Misch (referred to in this study as C-1) is composed of "core" rocks of the Skagit

Metamorphic Suite, whose eastern boundary south of the border is the Hozameen Fault. In the study area, the equivalent of Skagit rocks, the Custer Gneiss, grades into the Hozameen Group (McTaggart and Thompson, 1967) along a "zone of shearing, metamorphism and intrusion," which Monger (1970) uses as a boundary for structural belts. Monger's boundary has been retained in order to separate metamorphic core rocks from overlying Hozameen volcanic and sedimentary rocks.

The western boundary of this belt is the Straight Creek Fault Zone, composed of the sub-parallel, graben-forming Hope and Straight Creek (i.e., Yale) Faults which merge with the Fraser River Fault Zone north of Boston Bar. Misch reports steep (60^{o}) easterly dips and drag folds along the Straight Creek Fault, indicating dip-slip movement, west side down. Right-lateral movement is also suggested by drag folds and changes in structural and metamorphic facies across the fault. Recent correlation of the Hozameen Group with the Fergusson Group, west of the Fraser River Fault Zone and 190 kilometers north of the fault-truncated Hozameen Group, suggests considerable right-lateral movement (Cameron and Monger, 1971).

Misch's western belt, "West of the Straight Creek Fault," is subdivided internally along the Shuksan and Church Mountain Thrust Faults. As the Church Mountain Thrust is considered a shallow subsidiary of the Shuksan, only the latter is considered a fundamental boundary in this study.

Between the Straight Creek and Shuksan Faults (subdivision C-2) are rocks of the Shuksan Metamorphic Suite, represented by the Darrington Phyllite (D). This suite was brought up along the westerly-directed Shuksan Thrust, believed to be deep-seated because of associated sheared ultramafic rocks and slices of Yellow Aster basement (YA).

West of the Shuksan Thrust, subdivision C-3 contains sedimentary units which are complexly folded and faulted (i.e., Church Mountain Thrust), but are notably less-metamorphosed than Shuksan rocks. Units in this belt are the Chilliwack Group (CH), Cultus Formation (C), and Nooksack Group (NK).

Misch described the Vedder Mountain metamorphic rocks (subdivision C-4) as a large slice of pre-Devonian (Yellow Aster) basement. Misch included Vedder Mountain with other basement slices associated with the Shuksan Thrust, but because of its size, post-Devonian age, and distal position from the fault, it is placed as a separate tectonic unit in this study. Its eastern contact with C-3 sedimentary units is a steeply-dipping fault; Monger (1970) believed a similar fault lies to the west, buried in alluvium.

Descriptions of units within the Cascades, their deformational history and temporal relationships follow.

C-1: Crystalline Core Rocks

This subdivision represents the northern extension of the Cascade "core," described by McTaggart and Thompson (1967) as the Custer Gneiss. Banded, migmatitic, augen gneiss is closely associated with coarse pegmatitic bodies; amphibolite, metasedimentary and meta-ultramafic schist, marble, skarn and quartzite are present in lesser amounts. In places the Yale intrusions are identical in appearance to portions of the Custer Gneiss. Almandine amphibolite facies metamorphism dominates Custer rocks, and granulite facies is present locally.

McTaggart and Thompson believe the Custer Gneiss was formed by isochemical metamorphism and migmatization of the Hozameen Group; the contact between units represents a migmatitic front which cuts across layering of Custer and Hozameen units at a low angle. Highly sheared and recrystallized rocks in the transition zone indicate that movement also occurred along the zone separating the two units.

Timing of gneiss formation is not known accurately. Misch suggested that Skagit Metamorphism may be synchronous with formation of the Shuksan Suite (see below) which recent work by R. L. Armstrong (personal communication, 1977) has shown to span the Late Jurassic to Lower Cretaceous interval. This age is considerably younger than Misch's published estimate, determined on stratigraphic and structural grounds. Skagit Metamorphism is assumed to extend from uppermost Jurassic through major mid-Cretaceous orogeny (R. L. Armstrong, personal communication, 1977).

The Custer Gneiss is overlain unconformably by Eocene Chuckanut (CK) conglomerate and sandstone which represent continental trough deposits between the Hope and Yale Faults. In the study area Chuckanut rocks consistently occur along the east side of the Hope Fault. It is debatable whether or not the Chuckanut Formation has been folded, for the geometry of the unit in the study area may be a result of deposition along an active fault zone. Just south of the border, Staatz, et al., (1972) report that the Chuckanut Formation has been gently folded, but only tilting was noted near the border.

Oligocene Skagit (SK) volcanic rocks were deposited unconformably on Custer Gneiss; they cover the Custer/Hozameen contact and late Eocene plutonic rocks south of the border, but are intruded by late Oligocene intrusive phases of the Chilliwack Batholith. The unit, which resembles the Coquihalla Group, consists of 5,000 feet of gently folded volcanic flows and pyroclastic rocks of andesitic to rhyolitic composition.

The Chilliwack composite batholith, composed of tonalite, granodiorite and quartz monzonite, is a high-level intrusion in which three main phases are recognized: Chilliwack batholith, Mt. Barr batholith, and Silver Creek Stock (Richards and McTaggart, 1976). Hornfelsic contact aureoles are characteristic of these intrusions which cut across all earlier Cascade structures. These young plutons (40-16 Ma in the study area) generally are associated with volcanic rocks of similar ages (i.e., Skagit volcanic rocks); this association typifies the Cascade Belt which extends southerly into northern California.

Development of the western boundary of the Custer Gneiss occurred during movement of the Straight Creek Fault. Misch bracketed movement between faulted Paleocene Chuckanut strata and upper Eocene intrusions which cut the fault south of the border. However, Eocene Chuckanut strata in the study area are cut by the fault, contradicting Misch's estimate of an upper limit to fault movement. If Chuckanut strata were assumed to have been deposited during fault movement, possibly as a consequence of movement, then an Eocene and Paleocene age could be envisioned, with no lower limit other than mid-Cretaceous.

C-2: Shuksan Thrust Plate

The Shuksan Suite represents highly schistose rocks of the westerly-directed Shuksan thrust plate, confined between the Shuksan and Straight Creek faults. South of the border, this suite consists of a thick meta-basalt sequence (Shuksan Greenschist) overlying graphitic phyllites and schistose metagreywackes (Darrington Phyllite). The upper unit has not been reported north of the border, but Misch's 1977 map of the Northwest Cascades implies the continuation of a Darrington/Yellow Aster assemblage north to an area which was previously described as Chilliwack/Yellow Aster (Monger, 1970; Roddick and Okulitch, 1973).[5]

The Darrington unit (D) is a terrigenous sequence of phyllites and schistose metagreywackes which Misch believes to be derived from a clastic

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[5]Monger's description of cherty pelites, limestone pods, relict volcanic textures in amphibolites and possible altered Permian fusilinids strongly suggests a Chilliwack assemblage, but the implications of Misch's 1977 map have been adopted here as they were by Richards and McTaggart (1976).

sequence which has no non-metamorphic equivalents in the Cascades. South of the border, the overlying Shuksan Greenschist is characterized by high pressure lower blueschist facies metamorphism; Brown (1977) estimates operative pressures of seven kilobars. The nature of metamorphism of the Darrington Phyllite in the study area is not known, but assumed to be similar to that of the Shuksan Greenschist as described above.

Deep-seated thrusting along the Shuksan Thrust brought up not only the Darrington, but also slices of basement material (Yellow Aster Complex) and ultramafic rocks. Along the east side of the Shuksan Thrust, Roddick and Okulitch (1973) show a large slice of Yellow Aster (YA) which Monger (1970) described as coarse, locally well-foliated amphibolites and diorites, and massive, fine-grained amphibolites. Serpentinite lenses were also reported to parallel foliations in amphibolitic rocks composed of fifty percent hornblende with epidote, sphene and plagioclase. Formation of basement material probably occurred in Silurian and Ordovician, based on pebbles of Yellow Aster in Devonian conglomerate and isotopic age determinations of zircons in Yellow Aster rocks immediately south of the border (Mattinson, 1972). Emplacement of basement material in this section occurred during Shuksan thrusting.

Isotopic dates place metamorphism of the Shuksan Suite in uppermost Jurassic and Lower Cretaceous; deposition is believed to have occurred shortly before, in Middle and Upper Jurassic (R. L. Armstrong, personal communication, 1977). These estimates comply with the restriction by Misch that "Shuksan Metamorphism pre-dates the mid-Cretaceous emplacement of the thrust plate and bears no genetic relation to that tectonic event."

Movement along the Shuksan Thrust occurred in mid-Cretaceous time. Time constraints are post-Valanginian and pre-Santonian, in reference to faulted Nooksack Group rocks and Nanaimo Group sedimentary rocks which overlie the fault. Intense deformation accompanied thrusting near the fault, and imbrication is characteristic.

C-3: Western Flanking Units

Sedimentary rocks dominate this section beneath the Shuksan plate. Chilliwack (CH), Cultus (C) and Nooksack (NK) rocks represent a long period of deposition which began in Pennsylvanian and continued until major mid-Cretaceous orogeny, except for one interval of possible nondeposition around the Permo-Triassic boundary.

The Chilliwack Group is a sequence of clastic rocks, limestones and volcanic rocks. Pelite, siltstone and fine-grained sandstone form the "base" of the unit along the Church Mountain Thrust (true base is not exposed). The "base" contains local arenaceous shallow-water limestone pods with Lower Pennsylvanian crinoids.[6] Coarse sandstone and conglomerate record a period of uplift (after deposition of Pennsylvanian units) followed by pelites, tuffs and up to 2,000-foot sections of Lower Permian limestone. The top of the sequence contains arc-type eugeosynclinal volcanic rocks ranging from pillowed basalt to dacitic pyroclastic rocks (Misch, 1977). Ribboned chert is interbedded with volcanic rocks, generally stratigraphically equivalent to or conformably overlying Pennsylvanian limestone. Monger (1970) states that this stratigraphic sequence is applicable only to the area south of the Fraser River. Lowes (1972), who studied the area north of the Fraser River (see Figure 2-5, below), characterized the sequence as a varied sedimentary succession overlain by volcanic rocks, but he did not emphasize the presence of limestone.

Monger states that the Chilliwack Group closely resembles the Hozameen Group lithologically, but the presence of a larger amount of

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[6] The time-space plot shows the base of the Chilliwack Group extending into Devonian, as considerable Devonian limestone occurs south of the border (Danner, 1976).

clastic material and evidence of near-shore deposition and subaerial erosion point to an environment of deposition that is not known elsewhere in southwestern British Columbia. The disconformable contact between Chilliwack and Cultus units is the result of either gentle upwarping (reflecting a deep-seated phenomena), or rapid accumulation of the uppermost volcanic rocks so that a shallow basin could not be maintained.

The base of the Cultus Formation is a thin, sporadic breccia layer containing clasts of underlying Chilliwack volcanic rocks. Above this breccia is a sequence of fine, turbiditic sediments which span the Late Triassic to mid-Late Jurassic interval. The Cultus Formation is a rather uniform section of alternating graded beds of pelite, siltstone and fine sandstone with rare coarser varieties, cherty pelites and limestone pods.

The Upper Jurassic to lowermost Cretaceous Nooksack Group has been described only by Misch south of the border, although Monger's uppermost Cultus Formation is temporally equivalent and lithologically similar. The most recent maps by Roddick and Okulitch (1973) and Misch (1977) show an area of Nooksack Group west of the westernmost Cultus exposures, but the contact is covered by alluvium. Deposited in a trench environment, the Nooksack Group consists of rapidly-accumulated, volcanically-derived greywackes, siltstones and slates with local conglomerate, turbidite, clay and volcanic intercalations, characterizing a deep marine basin with local highs.

The outstanding structural features of this section are thrust faults and folds associated with Shuksan thrusting. The Church Mountain Thrust is considered a shallow off-shoot of the Shuksan "root zone," uplifting Chilliwack and Cultus rocks. Near the base of the Shuksan, slices of basement and serpentinized peridotite are imbricated with Chilliwack rocks of albite-epidote amphibolite facies metamorphism. The Cultus and Nooksack units occur below the Church Mountain Thrust; they are generally believed to be autochthonous, simply because there is no evidence that they have been transported significantly.

Tight, northwesterly overturned folds reflecting thrust geometry were formed during thrusting; penetrative slaty cleavage and phyllitization also formed, especially in finer-grained rocks. The same time constraints have been placed on Church Mountain thrust movement as for the Shuksan; the possible time span for movement centered around mid-Cretaceous time.

South of the Fraser River a second episode of folding was accompanied by reverse faulting, both affecting the older, major thrust planes. This episode is dated tentatively as Eocene, when the Chuckanut Formation was also folded slightly.

Metamorphism of Chilliwack and Cultus rocks in this area occurred under moderate total pressures and high thermal gradients characterizing metamorphic conditions between prehnite-pumpellyite and blueschist facies (Beaty, 1972).

North of the Fraser River, Lowes (1972) characterizes metamorphism of the Chilliwack Group as being distinctly higher grade than in correlative rocks to the south. An increase in metamorphic facies occurs from west to east from greenschist to upper epidote amphibolite facies as the Shuksan Thrust is approached. These higher grade rocks are garnetiferous and hornblende-rich schists. Monger noted that faults correlative with the Shuksan and Church Mountain Thrusts in this northern area dip steeply to the east in contrast with their relatively flat-lying counterparts to the south.

C-4: Vedder Mountain Wedge

Basement rocks on Vedder Mountain, southwest of Hope, belong to the Yellow Aster Complex of "ancient" continental crust (Misch, 1966). Misch describes the area as an autochthonous fault wedge of a "highly crystalline, metamorphic-plutonic complex." Upper amphibolite facies metamorphism of Yellow Aster rocks is accompanied by younger tectonic slices of albite-epidote amphibolite facies rocks which were dated at 250 Ma (lowermost Upper Permian), and believed by Misch to represent a younger metamorphic episode than that which affected the surrounding Yellow Aster Complex. More recent Rb/Sr dates by R. L. Armstrong (personal communication, 1977) show that Vedder Mountain "basement" was formed in Upper Permian to Lowermost Triassic time; parent rocks are probably Pennsylvanian to Lower Permian.

The western edge of Vedder Mountain is buried in alluvium, but is probably a fault, as the nearest outcrops to the west are of slightly metamorphosed Jurassic volcanic rocks and intrusions of the Coast Plutonic Complex.

SPUZZUM PLUTONIC BELT

The Spuzzum Plutonic Belt is named after the intrusions which dominate it, but minor amounts of Tertiary volcanic rocks and metamorphic rocks of pre-Spuzzum age are also present. The belt is delineated by the Fraser River Fault Zone and the Hope Fault on the east, the southernmost extension of the Spuzzum intrusions, the northerly extension of the Shuksan Thrust, and a hazy boundary to the west between Spuzzum and Scuzzy intrusions enclosing Paleozoic (?) pendant rocks, and the Coast Plutonic Complex with its much more varied assortment of pendants. In this belt Cascade and Coast Plutonic structures merge. All pre-Spuzzum units have been designated as either Custer Gneiss or Settler Schist; positive correlation is not yet possible, but evidence will be cited below which lends support to this suggestion. Units in this study are labelled according to Roddick and Okulitch (1973).

Metamorphic Rocks

Less than 30 percent of the Spuzzum Plutonic Belt is composed of highly metamorphosed (amphibolite grade) pendant rocks which have been studied in detail by various persons. Figure 2-5 shows the study areas of certain workers mentioned in the following discussion.

Referred to as Chilliwack Group on GSC Map 737A and as Hozameen Group by McTaggart and Thompson (1967) and Roddick and Hutchison (1969), Lowes (1972) suggests that this uniform sequence of aluminum-rich pelitic schists and metamorphosed siltstones and sandstones should be distinguished from the varied sequences of Chilliwack and Hozameen Groups. Localized metamorphosed breccias and quartz pebble conglomerates, amphibole-bearing schists, amphibolite and quartz feldspar porphyry dikes also characterize the Settler Schist (SS). Pigage (1976) suggests that original rock types of the Settler Schist characterize a eugeosynclinal environment of shales and less common interbedded carbonate-rich layers, conglomerates, tuffs and sandstones or cherts.

The type area of the Settler Schist is east of Old Settler Mountain, southwest of Yale. As set out by Lowes, the Settler Schist is confined by the Hope Fault on the east and the northward extension of the Shuksan Thrust on the west (discussed below), continuing northward to the area described by Hollister (1969a,b) northwest of Boston Bar.[7]

Lowes concluded that Barrovian amphibolite facies metamorphism of unknown age was upgraded by another contact-metamorphic event resulting from intrusion of the Spuzzum Pluton. Pigage concluded that two metamorphic-

[7]Hollister describes this area as dominated by greywacke, and reports some pillowed amphibolite. The long, narrow belt of northwest-trending serpentinite is correlated with the Hozameen Fault by Roddick and Hutchison (1969). This move also suggests that the pendant is a Hozameen and Ladner combination, but this idea has been abandoned for a more northerly Hozameen correlation, and Lowes believes the pendant to correlate with the Settler Schist.

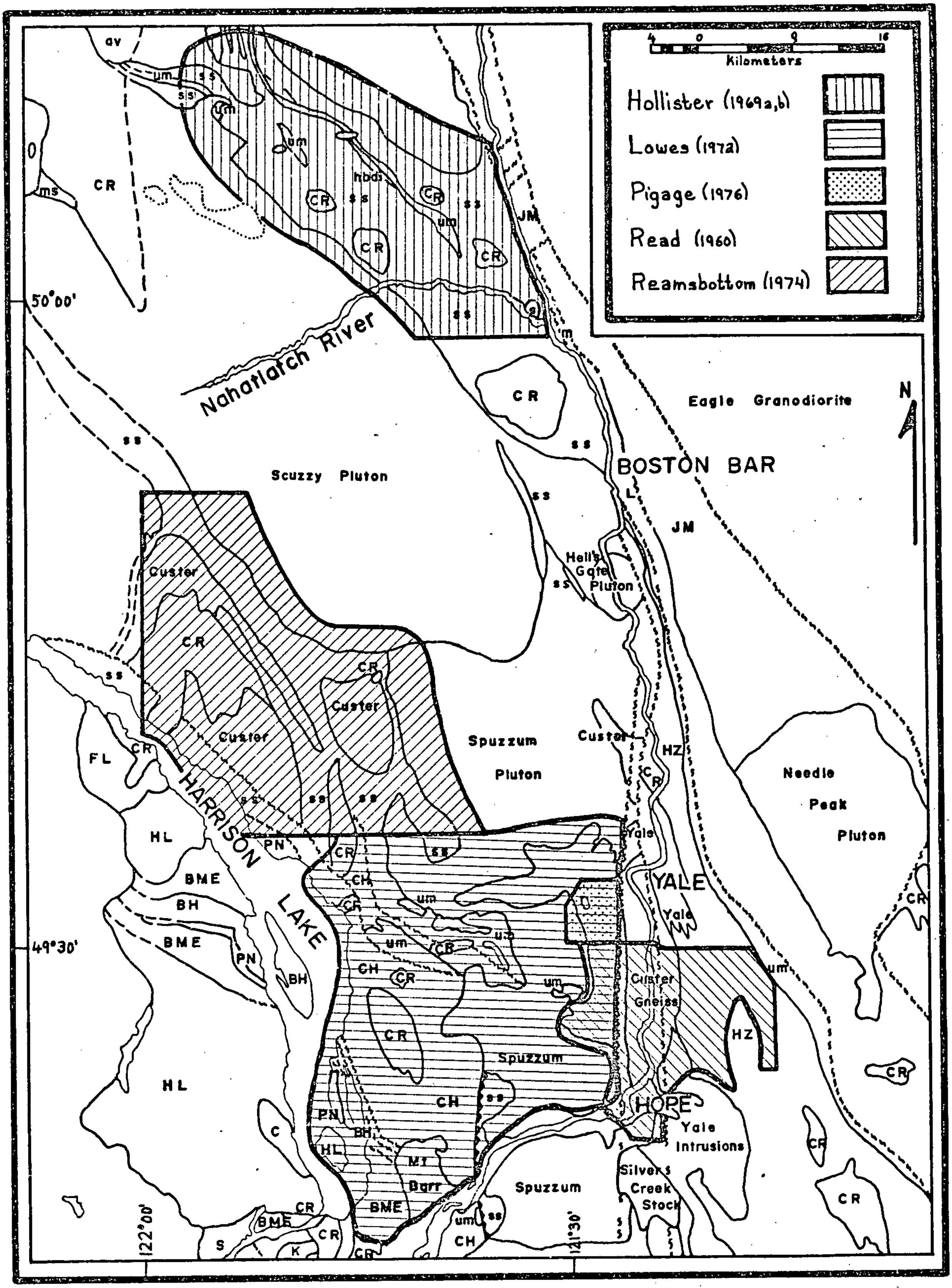

Figure 2-5. Study areas of some principle workers dealing with the metamorphic rocks of the Spuzzum Plutonic Belt. Refer to Table 2-1 for definition of abbreviations.

deformational events affecting the Settler Schist were continuing phases of the same Late Cretaceous orogeny during which the Spuzzum Pluton was emplaced. Hollister considered metamorphism to be the result of one deep-seated prograde contact-metamorphic event occurring during intrusion of surrounding plutons. These conflicting opinions are a consequence of structural and metamorphic relations which have yet to be resolved.[8] This study follows Lowes' assumption that an older event which pre-dates Spuzzum intrusion must have occurred prior to uplift along the Shuksan Fault east of Harrison Lake (see discussion below).

Regardless of when metamorphism occurred, it is generally considered to be deep-seated. Hollister (1969a) estimated effective pressures between 5.5 and 7.1 kilobars; Pigage (1976) estimated pressures between 5.5 and 8.0 kilobars (18-26 kilometers) and temperatures between 550-700^{o}C.

Information on the area northeast of Harrison Lake has been summarized from work by Reamsbottom (1974), who identified two conformable stratigraphic units which he called the Breakenridge and Cairn Needle Formations. The Breakenridge Formation is composed of gneiss with amphibolite, minor migmatite and skarn; the pre-metamorphic assemblage is believed to be a mixture of greywacke, volcanic rocks and minor pelite. The base of the overlying Cairn Needle Formation is a stretched-pebble conglomerate which contains

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[8] It seems that the major difficulty lies in the fact that andalusite appears to be a contact-metamorphic effect of the Spuzzum and Scuzzy intrusions; Read (1960), Hollister (1969a,b), Lowes (1972), and Pigage (1976) all noted the presence of chiastolite pseudomorphs in the Settler Schist near plutons. However, Pigage noted that pseudomorphs in his area contain products of regional kyanite-sillimanite metamorphism, suggesting that this higher pressure regional event followed intrusion of the Spuzzum. Slight tilting after intrusion is proposed to have caused this increase in pressure. Hollister suggests that andalusite is formed metastably under the same conditions that formed kyanite and sillimanite, and therefore requires only one episode of metamorphism with increasing temperature. These suggestions do not agree with conclusions reached by Lowes that an early period of deformation must have occurred before uplift along the Shuksan Thrust and intrusion of the Spuzzum pluton.

granitic clasts and indicates slight uplift before deposition of the Cairn Needle Formation. Above the conglomerate are meta-sedimentary schists (some pelitic) with minor calc-silicate schist and limestone. Pelites, conglomerate and limestone indicate a varied shallow marine environment.

Reamsbottom correlated the Breakenridge with the Custer Gneiss and noted that the Cairn Needle merges to the south with the type area of Lowes' Settler Schist which is also probably part of the Skagit Metamorphic Suite.[9] Granitoid clasts in Cairn Needle conglomerates suggested to Reamsbottom that deposition may have occurred post-Coast Plutonic Complex, but Paleozoic conglomerates have also been known to contain such material. Age of these units is therefore assumed to correspond to that of the Custer Gneiss.

Reamsbottom delineated four phases of essentially homoaxial pre-Late Cretaceous folding, which affected both units to the same degree. One of the later phases produced large, gneiss-cored, northwesterly-trending dome structures. Amphibolite facies Barrovian metamorphism was synchronous with folding before mid-Cretaceous faulting.[10]

The distinction of the southwestern boundary of the Spuzzum Belt lies in Lowes' continuation of the Shuksan fault into his area. Factors which led to his conclusion include the following:

1) The presence of rocks similar to the Yellow Aster Basement Complex;

2) ultramafic rocks (some of which he likens to alpine-type dunites) whose contacts appear to be tectonic;

3) truncation of metamorphic isograds; and

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[9] It is interesting to note that the varied Cairn Needle assemblage includes limestone and appears to contrast with Lowes' uniform pelitic sequence which has a notable lack of limestone.

[10] Chiastolite pseudomorphs were also recognized by Reamsbottom as a contact effect of Scuzzy intrusion. Whereas pseudomorphs in Pigage's area contain staurolite, those in Reamsbottom's area contain sillimanite, which does not require an increase in pressure.

4) juxtaposed dissimilar rock units.

Unfortunately, Reamsbottom was not able to extend the trace of the Shuksan Thrust any further northward, so the fault is shown as being the eastern boundary of rocks mapped as Chilliwack, and is not followed any further northward than are Chilliwack rocks.

An important outcome of Lowes' work is the implication that thrusting along the Shuksan in this area brought up rocks resembling schists of the Skagit Metamorphic Suite instead of the Shuksan Suite which forms the Shuksan plate to the south. The conclusion that this belt represents the northward continuation of the Cascade core axis at a much deeper structural level is attractive.

Intrusive Rocks

The Giant Mascot body is a large, crudely-zoned ultramafite located centrally within the Spuzzum pluton; isotopic ages place it in the Lower to mid-Cretaceous interval. It has been suggested that the Giant Mascot body is an early phase of Spuzzum activity (McLeod, 1975), but the relationship between ultramafic rocks and Spuzzum diorite and tonalite is not known with certainty, other than the fact that the latter intrudes the former (Vining, 1977). It is interesting to note that the Giant Mascot body also lies at the southeastern end of a northwesterly-trending belt of ultramafic rocks which are believed to have been emplaced tectonically along the mid-Cretaceous Shuksan Thrust. Unfortunately, the connection between Giant Mascot and the Shuksan belt is masked by the Spuzzum pluton.

The Spuzzum and Scuzzy plutons are considered to be the easternmost extension of the Coast Plutonic Complex, and yield Cretaceous K/Ar dates (see Figure 2-2) that correspond to the major pulse of Coast Plutonic intrusion. Richards and McTaggart (1976) show the Spuzzum as a zoned intrusion of three dioritic phases surrounded by a later margin of tonalite (quartz diorite). The Scuzzy pluton was considered younger than the Spuzzum pluton (Roddick and Hutchison, 1969) because of a supposed genetic relationship between Scuzzy and Hell's Gate plutons (see below), but K/Ar dates have not been able to distinguish Scuzzy and Spuzzum plutons as separate intrusive events. The Scuzzy is lithologically distinct from the Spuzzum, composed of coarse granodiorite with less than five percent mafic content, contrasting with the 15-25 percent mafic content of the Spuzzum.

Hell's Gate pluton is an Eocene to Oligocene fine-grained intrusion of granodiorite that is truncated by the Straight Creek Fault.

Tertiary Volcanic Rocks

The only reference to Miocene-Pliocene acid volcanic rocks (av) appears in Roddick and Hutchison (1973), who admit that the age of these rocks is "little more than a deflected guess." Unconformable on plutonic rocks and generally flat-lying with local dips of 30° or less, these volcanic rocks are remnants of a "once extensive cover of . . . rhyolitic to dacitic pyroclastics and flows."

COAST PLUTONIC BELT

Fifty-five percent of the study area consists of rocks of the Coast Plutonic Belt, a tectonic province with about 20 percent non-plutonic rocks which occur as pendants or remnant units. Most pendant rocks are either highly deformed and metamorphosed or regionally altered during intrusion of plutonic rocks, although local unaltered areas are known. Cover units are dominantly volcanic and volcano-sedimentary, although a sedimentary record of erosion of the Coast Range is preserved in the southernmost portion of the belt.

Pendant Rocks

Older Units of Unknown Age

The oldest named units which occur as pendants in the Coast Plutonic Belt are the Twin Islands (TI) and Bowen Island (BI) Groups. Except where noted, information concerning these units was obtained from Roddick (1965).

The Twin Islands Group forms small pendants which commonly appear to grade into surrounding intrusive rocks through migmatitic zones. Rock types include granulite, amphibolite, micaceous quartzite, phyllite, schist and gneiss, with minor quantities of conglomerate, meta-andesite, rhyodacite and hornfels. Metamorphism is generally high-grade (i.e., upper amphibolite), but examples of pendants containing small, scarcely-altered areas are reported. This group is a catch-all for rocks which have undergone a period of intense metamorphism and therefore may include rocks of varying ages. Age of the group is estimated as Pennsylvanian-Permian according to Roddick and Okulitch (1973). Highly metamorphosed conglomerates contain cobbles of plutonic rocks which must have been derived from an older plutonic terrane. At the northern end of Harrison Lake, rocks mapped by Roddick as Twin Islands Group correspond to a section of Reamsbottom's Cairn Needle Formation (Custer Gneiss), also of unknown age. A large pendant northeast of Squamish is mapped as having Twin Islands Group in the south and younger, less-deformed Gambier Group (G) in the north (see below).

The Bowen Island Group occurs on and near Bowen Island. It is dominated by massive, andesitic greenstone flows with minor interbedded sedimentary rocks, which are thinly-banded, cherty and tuffaceous. Metamorphism is up to greenschist facies. Several thousand feet of strata are thought to be present. The age of this group is unknown, but is placed at

Lower to mid-Upper Triassic because Roddick believed it to be older than the Cultus Formation and younger than the Twin Islands Group.[11] Roddick and Okulitch (1973) placed the Bowen Island Group in the Triassic.

Three unnamed units of unknown age are shown as "m," "ms," and "gn" on Figure 2-1, but do not appear on the time space plot (Figure 2-2). Many possibly are more highly metamorphosed equivalents of surrounding units. Only brief descriptions are available for each as follows:

m: Undivided metamorphic rocks including gneiss, schist, hornfels, metavolcanic rocks, quartzite, greywacke, slate, argillite, migmatite, and agmatite (Bostock, 1963).

ms: Metasedimentary rocks including micaceous quartzite, biotite-hornblende schist, schists bearing garnet, staurolite and possibly sillimanite (Roddick and Hutchison, 1973).

gn: Gneissic units including granitoid gneiss, migmatitic complexes, and minor amphibolite and biotite schist (Roddick and Hutchison, 1973). Roddick and Okulitch (1973) correlated some of these pendants with the Twin Islands Group or Custer Gneiss.

Harrison Lake Sequence

A short interval of volcanism on the west side of Harrison Lake in Bajocian (lowermost Middle Jurassic) time was followed by sporadic sedimentation through Hauterivian (mid-Lower Cretaceous) time. Fossils have been of great importance in determining ages of these units, a rarity for Coast Plutonic Belt pendant rocks whose fossil ages are generally indeterminate. Information concerning these formations is taken from Monger (1970), except where noted.

Approximately 9,000 feet of intermediate to acid pyroclastic and flow rocks make up the Harrison Lake Formation (HL). Rock types include kerato-

[11] The latter restriction is based on the lesser degree of metamorphism, but he also suggests that it may be a less-metamorphosed equivalent of the Twin Islands Group.

phyre, quartz-keratophyre, meta-andesite and dacite. Pyroclastic rocks include volcanic breccias with fragments up to one foot in diameter and lithic and crystal tuffs; flows are commonly porphyritic, massive, or locally columnar jointed. Fossils indicate a Bajocian age, and possibly also Bathonian. This formation conformably overlies sandstone, black argillite and tuff labelled as Cultus Formation, but whose identity and age are, in fact, unknown. Contemporaneous volcanism similar to that of the Harrison Lake Formation occurred south of the border in the Cascades (Misch, 1966).

Conformably overlying the Harrison Lake Formation is a series which includes the Echo Island, Mysterious Creek and Billhook Creek Formations, grouped together on the compilation map (Figure 2-1) for convenience as BME. Waning volcanism is represented by nearly 3,000 feet of well-stratified, fine-grained tuff and minor agglomerate, sandstone, and argillite of the Echo Island Formation. Two to three thousand feet of uniform black calcareous argillite of the Mysterious Creek Formation overlie Echo Island, and contain mid-Callovian fossils. These argillites grade upward into the Billhook Creek Formation, composed of fine tuffs and volcanic sandstones with an apparant thickness of 1,800 feet. This gradational relationship implies the Billhook was deposited during upper Callovian; Brookfield (1973) also reports lower Oxfordian fossils. These three formations are found west of Long Island in Harrison Lake as a conformable series which was mapped by Roddick on the adjacent western map sheet as the Fire Lake Group (FL) which is discussed below.

Three thousand feet of poorly-sorted conglomerate (notably without granitic pebbles) of the Kent Formation (K) is sandwiched between two black argillaceous units south of Harrison Lake. Argillite occurring conformably (?) below the conglomerate is believed to be the mid-Callovian Mysterious

Creek Formation; the section above is referred to as the Agassiz Prairie Formation (AP). Interbeds of sandstone, tuff and limestone are also present within this upper argillite sequence. If Oxfordian argillites on the Cascade Peninsula can be considered to be Agassiz Prairie Formation, the Kent Formation must also be Oxfordian, but Brookfield (1973) considered the Cascade Peninsula outcrop to be equivalent to the Billhook Creek Formation, in which case both the Kent and the Agassiz Prairie Formations can only be referred to as post-Oxfordian.

Conglomerate with granitic pebbles which resemble intrusive rocks occurring seven miles west of Harrison Lake, forms the base of the 1,260-foot thick Peninsula Formation (PN) which rests with angular unconformity on the Billhook Creek Formation. Arkosic sandstone forms the remainder, and Lowes (1972) reports layers of limestone. Berriasian and lower Valanginian fossils have been described. This formation may in fact be the Nooksack Group, as they are temporally equivalent. Nooksack conglomerate on Vedder Mountain was mapped by Monger as possible Peninsula Formation because of similar clast material.

Conformable above the Peninsula Formation is the 3,700-foot thick Brokenback Hill Formation (BH) of Valanginian, Hauterivian, and possibly younger ages (the top is faulted against older rocks). Tuff and agglomerate with minor amounts of sandstone and shale form a lower section overlain by bedded greywackes. Roddick (1965) mapped the westernmost extensions of the Peninsula and Brokenback Hill Formations as Fire Lake Group(FL).

Fire Lake and Gambier Groups; Pioneer Formation

The Fire Lake Group (FL) is described in detail by Roddick (1965). Berriasian fossils were located in limestone of the lower member of the group, and it includes Bathonian, Callovian and Oxfordian units described above. The questionable extension up into Albian time is a result of lithologic correlation with the Gambier Group.

Lithologic divisions within the Fire Lake Group are based on units of the large pendant northwest of Harrison Lake. A lowermost section of fine-grained granulite[12] and minor andesite, limestone and conglomerate is overlain by a section of slate and argillite with minor amounts of greywacke. Above these units is a thick greenstone member with some conglomerate, quartzite and greywacke. Conglomerates contain appreciable granitic detritus, but some plutons are cross-cutting. The thickness of the group is estimated at 15,000 feet. Metamorphism of all units is slight except for the lowermost granulite unit which is amphibolite facies.

The Gambier Group is characterized by andesitic to dacitic volcanic and sedimentary rocks whose complexity, rapid facies changes and paucity of fossils make correlations between pendants difficult. However, the general character of volcanism has led to the designation of rocks in an increasing number of pendants as Gambier Group. On Gambier Island, Gambier Group rocks unconformably overlie Upper Jurassic plutonic rocks (McKillop, 1973); later plutons intrude pendant rocks.

Roddick (1965) describes an approximately 6,000-foot section east of Gambier Island with three subdivisions lying unconformably (in places vertically) on plutonic and metamorphic rocks. A basal conglomerate with granitic cobbles is overlain by andesitic flows and pyroclastic rocks of the lowermost division. The middle unit consists of slate, argillite, arkose and quartzite. Andesite and tuff comprise the upper unit whose top has been removed by erosion. Albian ammonites were recovered from slaty

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[12]Roddick (1965) defines granulite as "a feldspathic metamorphic rock having a relatively even granular texture, similar to an amphibolite, but containing less than 50 percent amphibole. Most of these rocks fall in the amphibolite facies . . . not the granulite facies . . . ."

argillite in this area.

The large pendant north of this section was described originally by James (1929) as the Britannia and Goat Mountain Formations. Here an almost 20,000-foot section whose sequence differs slightly from that to the south is similar lithologically.

The Cheakamus, Empetrum and Helm Formations (CEH) were described originally by Mathews (1958) as Upper Cretaceous sedimentary rocks north of Squamish, but recent reassignment of fossils found in the Cheakamus Formation implies a Lower Cretaceous age (Roddick, et al., 1977).[13] Basal conglomerate of granitic and greenstone pebbles similar to that of the Gambier Group, along with a Lower Cretaceous age and the fact that formations are cut by later intrusive phases has led to the inclusion of these formations in the Gambier Group. The sequence here is not clear, as formations are in fault contact with each other, but there appears to be more than 20,000 feet of section. Several thousand feet of volcanic rocks are present and sedimentary rocks appear to contain an appreciably higher proportion of coarser-grained units than to the south. Limestone and limy sedimentary rocks also appear to be more common here.

The Pioneer Formation, of Norian age, originally referred to a small, 1,000-foot section of variable greenstones (with minor amounts of rhyolite) north of the study area near Bralorne, but was extended southward on fossil evidence by Roddick and Hutchison (1973) to a 5,000-foot sequence north of Pemberton. An unpublished map by Woodsworth (ca. 1975) extended the formation even further south to include two sub-parallel pendants north of Garibaldi. Roddick and Okulitch (1973) consider these same pendants as part

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[13] Green (1977) suggests that the Empetrum is not part of this section, but pre-Cretaceous, as it contains highly metamorphosed rocks, and dolomitic interbeds within the greenstone.

of the Fire Lake Group, whereas Roddick, et al., 1977, and Woodsworth, 1977, consider them Gambier Group. The most recent correlation with the Gambier Group has been adopted in this study, although it is by no means certain. No granitic pebble conglomerates have been reported in these northern pendants, and sedimentary rocks are a very minor component; limestone occurs locally. The overwhelming majority of pendant rocks are intermediate to acid pyroclastic and flow rocks. The western pendant has yielded one reasonable K/Ar date of 124 ± 4 Ma (see discussion of Northair Mine, Chapter Two).[14]

Greenschist facies metamorphism affected the majority of Gambier Group rocks. Deformation is localized along northwesterly-trending zones of intense foliation, many of which are pyritic. These foliated zones are commonly referred to as "shear zones," although in many it is questionable whether shear displacement has actually occurred. One such zone of major proportions in the Britannia pendant will be discussed in detail in Chapter Two.

Plutonic Rocks

Intrusive rocks representing the Coast Plutonic Complex (CR) in the study area are most commonly reported to be quartz diorite or granodiorite, but other types of coarse-grained granitic rocks (except syenite) are represented in lesser amounts. A northwesterly-trending foliation paralleling pendant contacts is common; contacts with pendants are sharp or gradational.

Included with rocks designated as plutonic are migmatitic complexes containing over 50 percent plutonic rock. Brittle deformation is generally exhibited in these rocks through faulting and/or brecciation (Roddick, 1965).

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[14] Green (1977) also considers these pendants pre-Cretaceous, specifically, Jurassic, but does not state what criteria led to this conclusion.

The earliest record of intrusive activity occurs on Gambier Island and near the north end of Howe Sound; K/Ar dates are Upper Jurassic. A 30 million year gap occurs before the main pulse of plutonism in upper Lower Cretaceous and Upper Cretaceous. One upper Paleocene date was obtained just outside the study area, south of Pemberton.

Post-Plutonic Rocks

Dominantly Eocene units exposed sporadically in the Fraser River delta area consist of sedimentary and basic volcanic rocks labelled "s" and "bv," respectively (Figure 2-1). Sedimentary rocks include sandstone, shale and conglomerate (some tuff and coal) which lie unconformably on plutonic rocks and thicken to about 9,000 feet south toward the United States border. Shales become dominant to the south, indicating a northern source (i.e., Coast Range), but younger units thicken southward, indicating a more recent southern source. These continental floodplain deposits contain mostly Eocene fossils, but late Campanian is recorded north of Burrard Inlet, and Roddick (1965) believed that younger, more southern units might be Oligocene. Rare basalt and tuff interbeds in the above-described sedimentary rocks are locally thick enough to map as a separate unit. Fine-grained, porphyritic basalt is locally columnar-jointed, but origin as flows or sills has not been determined. Dikes and rare pyroclastic rocks are also present.

Quaternary, calc-alkaline Cascade volcanism extends from northern California through Oregon and Washington, into British Columbia where it appears as the Pleistocene to Recent Garibaldi Group (GB; Green, 1977). Basalt, andesite and dacite flows were extruded on the glaciated surface of the Coast Mountains. There is evidence of extrusion contemporaneous with glaciation; pre- and post-glacial lavas flowed along present valley floors which are still occupied by rivers.

SUMMARY AND DISCUSSION

A tectonic summary of the study area is presented in Table 2-4, and a generalized discussion of a plate tectonic model follows.

The evolution of the Canadian Cordillera has been described as the development of a series of Upper Paleozoic-Lower Mesozoic volcanic arcs off the coast of the continental craton, successively added to the craton through subduction (Monger, et al., 1972). As each arc collided with the craton, the related subduction zone ceased to function, and another one began to operate west of the arc. Figure 2-6 illustrates this process and shows the locations of possible subduction zones in the Cordillera.

To relate this model to the study area, one can view the mid-Cretaceous event discussed above as resulting from collision between the Pacific Plate, carrying a volcanic-plutonic arc (Coast Plutonic Complex), and the craton, to which the Omineca and Intermontane Belts have also been added. Metamorphic core rocks of the Spuzzum and Cascade Belts mark the axis of compression, bounded by oppositely-verging thrusts (see Figure 2-1a), illustrating the compressive force which moved material up and away from the convergent zone.

Subduction responsible for the Coast Plutonic Complex ceased after mid-Cretaceous collision, although intermittent plutonism did occur through Miocene. Subduction responsible for Cascade volcanism is a more recent phenomenon which overlaps the Coast Plutonic arc in the study area, but does not continue far northward where plate interaction is of a transcurrent nature.

As suggested in Figure 2-6A, subduction was followed by right-lateral transcurrent motion. This change is illustrated in the study area by Upper Cretaceous compression followed by transcurrent movement in Lower Tertiary along the Straight Creek/Fraser River Fault System.

TABLE 2-4. SUMMARY OF TECTONIC HISTORY

	TIME SPAN	EVENTS	UNITS INVOLVED (see Figures 2-1, 2-2)
I.	Pre-Devonian	Formation of basement	YA in C-2
II.	Upper Paleozoic/ Lower and Middle Triassic	Marine eugeosynclinal deposition in a basin which shallows westward (or, if right-lateral offset is considered, shallows to the south).	CH,HZ (TI?,BI?,YA in C-4?)
III.	Permian/Triassic	Deformation	YA in C-4 (TI?,BI?)
IV.	Upper Triassic	Volcanism in the Coast Plutonic Belt and extensively east of the study area forming the Intermontane Belt. Deposition of marine turbidites begins in the southern section.	PI,N C
V.	Lower and Middle Jurassic	Deep-water deposition in the Ladner Trough begins from a high source area to the east. Deposition continues in the south, and a burst of acidic volcanism occurs on the eastern edge of the Coast Plutonic Belt, followed by deposition in local basins of varying relief.	L C,D HL,BME
VI.	Upper Jurassic	Plutonism of unknown extent in the Coast Plutonic Belt, and some deposition. Deformation and metamorphism begins along a north-south axis in the Spuzzum and Cascade Belts. Deposition of trench-like sediments along this axis begins. Shallow-water deposition of more easterly-derived sediments in the Ladner Trough and possible intrusion of the Eagle Complex.	CR,FL (AP?,K?) SS, Custer Gneiss D DC Eagle ?
VII.	Lower Cretaceous	Considerable marine volcanism and sedimentation in the Coast Plutonic Belt along with the beginning of intense plutonism and/or cooling of said plutons to the point where they have begun to retain argon to produce radiometric dates. Axial deformation continues, and the Giant Mascot Ultramafic body has also cooled sufficiently to produce K/Ar dates. Trench-like deposition along the metamorphic axis ceases by mid-Lower Cretaceous. Easterly-derived marine deposition continues in the Ladner Trough, but becomes westerly-derived and non-marine by the close of Albian time, indicating considerable uplift to the west, presumably of the Coast Plutonic Complex. The Eagle Complex is also shedding debris into the Ladner Belt by Albian.	G,CEH,FL,PN,BH CR SS, Custer Gneiss D um NK JM,P
VIII.	mid-Cretaceous (limits undefined)	Major thrusting directed away from the central metamorphic axis brought up mantle-derived (?) ultramafic rocks and basement material. Genetically-related folding accompanied thrusting in the Cascade Belt, Hozameen Basin and Ladner Trough. The Eagle Plutonic Belt was also uplifted at this time. Figure 2-1a illustrates this deformation episode, and includes later faulting as well.	Shuksan, Church Mountain, Hozameen, Pasayten Faults um Eagle
IX.	Upper Cretaceous	The majority of the Coast Plutonic Complex (and Spuzzum) K/Ar dates are clustered in this period, but by the end of Cretaceous time large-scale plutonism had ceased. Major deformation and thrusting in all areas have also ceased by latest Cretaceous.	CR, Spuzzum, Scuzzy
X.	Tertiary	The Coast Plutonic Belt records volcanism and sedimentation which began in latest Cretaceous, recording continued uplift and erosion of the Coast Mountains. One K/Ar date records late cooling/intrusion of plutonic rocks. Major right-lateral movement along the Straight Creek/Fraser River Fault Zones and related (?) sedimentation and intrusion occurred before Oligocene. High-level plutons are concentrated in the Cascade Belt, but are also scattered throughout the area; coeval volcanic rocks were extruded.	s,bv,CR Straight Creek/Fraser River Fault Zone, CK, Yale Intrusions Hell's Gate, Silver Creek, Chilliwack, Mt. Barr, Needle Peak av,SK,CQ
XI.	Pleistocene	Calc-alkaline volcanism occurred in the Coast Plutonic Belt.	GB

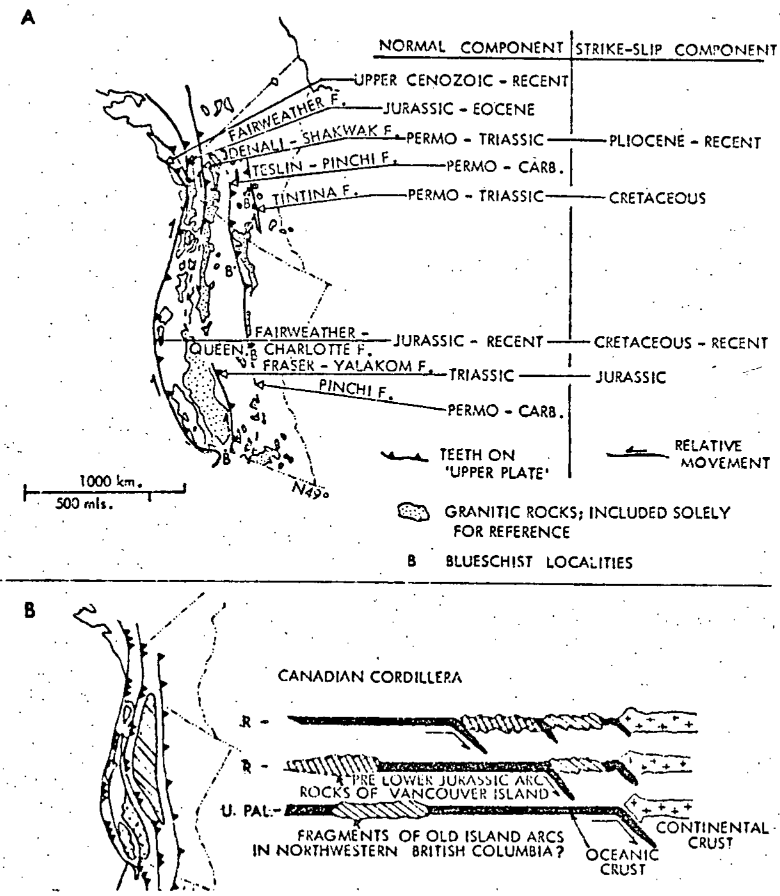

Figure 2-6. A. Possible subduction zones in the Canadian Cordillera; later transcurrent motion suggests oblique subduction.

B. Method of accretion of crustal blocks, resulting in westward "jumping-out" of subduction zones. (Transcurrent or normal plate interaction may be responsible for crustal accretion.)

(from Monger, et al., 1972)

3. METAL DEPOSITS

INTRODUCTION

Public records were examined for a total of 258 metal deposits in the study area (Figure 1-2), but thirty of these are not described adequately in the available literature except for location and perhaps general commodity data. Of the remaining 228 deposits, 86 percent are small occurrences that have never produced. A discussion of every deposit is not necessary to give the reader an appreciation of mineralization which characterizes the study area. An alternative approach is to present information only on deposits of the following three categories:

1) major mines and related occurrences
2) mining camps without major mines
3) isolated past-producers and important prospects

Table 3-1 is a compilation of production records from all deposits in the study area for which such information is available. Those producing deposits which are not included in discussions of districts and camps of the first and second categories outlined above will be presented and discussed briefly in the third section. Figure 3-1 shows locations of districts, camps and individual deposits which will be considered in this chapter. Tabulation of the characteristics of these deposits is presented with each discussion; abbreviations and symbols used in these tables are defined in Table 3-2.

Discussion of deposits in the categories outlined above will acquaint the reader with about two-thirds of the deposits in the area for which geological information is available. The remaining deposits, generally the smallest and least known of the publically documented occurrences in the study area, will not be discussed.

Mac No. Name	Production	Metals Produced[1]	Reference	Time of Production
G-3 Britannia	52,783,964 T	Cu,Zn,Pb,Ag,Cd,Au	BCDM[2]	1905-1974
G-5 Zel	?		MMAR[3]	prior to 1890
G-14 Lorraine	70 T	Cu,Zn,Ag	BCDM	1907,1917
G-23 Cambrian Chiefton	1,566 T	Cu,Ag (Au)[4]	BCDM	1949,1952,1961,1963
G-24 King Midas	95 T	Cu,Ag	BCDM	1940
G-25 Ashloo	15,047 T	Cu,Ag,Au	BCDM	1932-39
G-26 Money Spinner	200 lbs	Au	BCDM	1897
	1,500 T in dump and thousands of tons in sight		MMAR	
G-34 Viking	198 T	Cu,Ag	BCDM	1916
	16,000 T estimated present		MMAR	
G-36 Dandy	55 T (includes G-26)		GEM[5], 1972, p. 104	1897
	250,000 T estimated present		MMAR	
HSW-1 Canam	25 T		MMAR	prior to 1947
HSW-2 Invermay	99 T	Zn,Pb,Ag (Au)	BCDM	1936,1941,1947
HSW-4 Giant Mascot	6,081,133 T	Ni,Cu	GEM, 1974, p. 105-6	1933-1937, 1958-1974
HSW-8 Empress	100 T	Cu	BCDM	1917
HSW-11 Eureka-Victoria	1 high-grade shipment		MMAR	early 1870's
HSW-13 Seneca	287 T	Zn,Cu,Ag,Au	BCDM	1962
HSW-15 Valley View	50 T	Cu,Ag	BCDM	1961
HSW-16 Silver Chief	1 T	Ag,Cu	BCDM	1926
	130 T lead concentrate and 1 carload zinc concentrate		MMAR	1929,1956
HSW-18 Eureka	23 T		MMAR	1926
HSW-25 Silver Daisy	28 T	Pb,Zn,Ag (Au)	BCDM	1916,1929
HSW-33 Anna	1 carload		MMAR	1920
HSW-34 Emancipation	638 T	Au,Ag,Pb,Zn	BCDM	1916-1941
HSW-36 Aufeus	537 T	Cu,Ag,Au	BCDM	1937-1941
HSW-42 B.B. (Rainbow)	8 T	Ag	BCDM	1915
HNW-2 Providence	350 T		GEM, 1972, p. 104	1879-1899
HNW-3 Aurum	545 T	Au,Ag	BCDM	1930-1942
HNW-11 Pipestem	1,650 T	Cu,Au,Ag	BCDM	1935-1937
HNW-15 Ward	?	Au	BCDM	1905
J-45 Astra,Cambria	350 T	Pb,Cu,Ag (Au)	BCDM	1970
J-51 Van Silver	29 sacks of "selected" material shipped		MMAR	1934
J-130 Northair	67,100 T	Zn,Pb,Cd,Ag,Au	Northair Mines Ltd. Annual Report, 1977	1976-1977

[1] Metals are listed in decreasing order of amounts shipped if such information is available.

[2] British Columbia Department of Mines and Bureau of Economics and Statistics, Victoria, British Columbia

[3] Annual Reports of the British Columbia Minister of Mines

[4] Parentheses indicate very minor production; in the cases specified above less than 20 ounces of the metal was shipped.

[5] Geology, Exploration and Mining in British Columbia

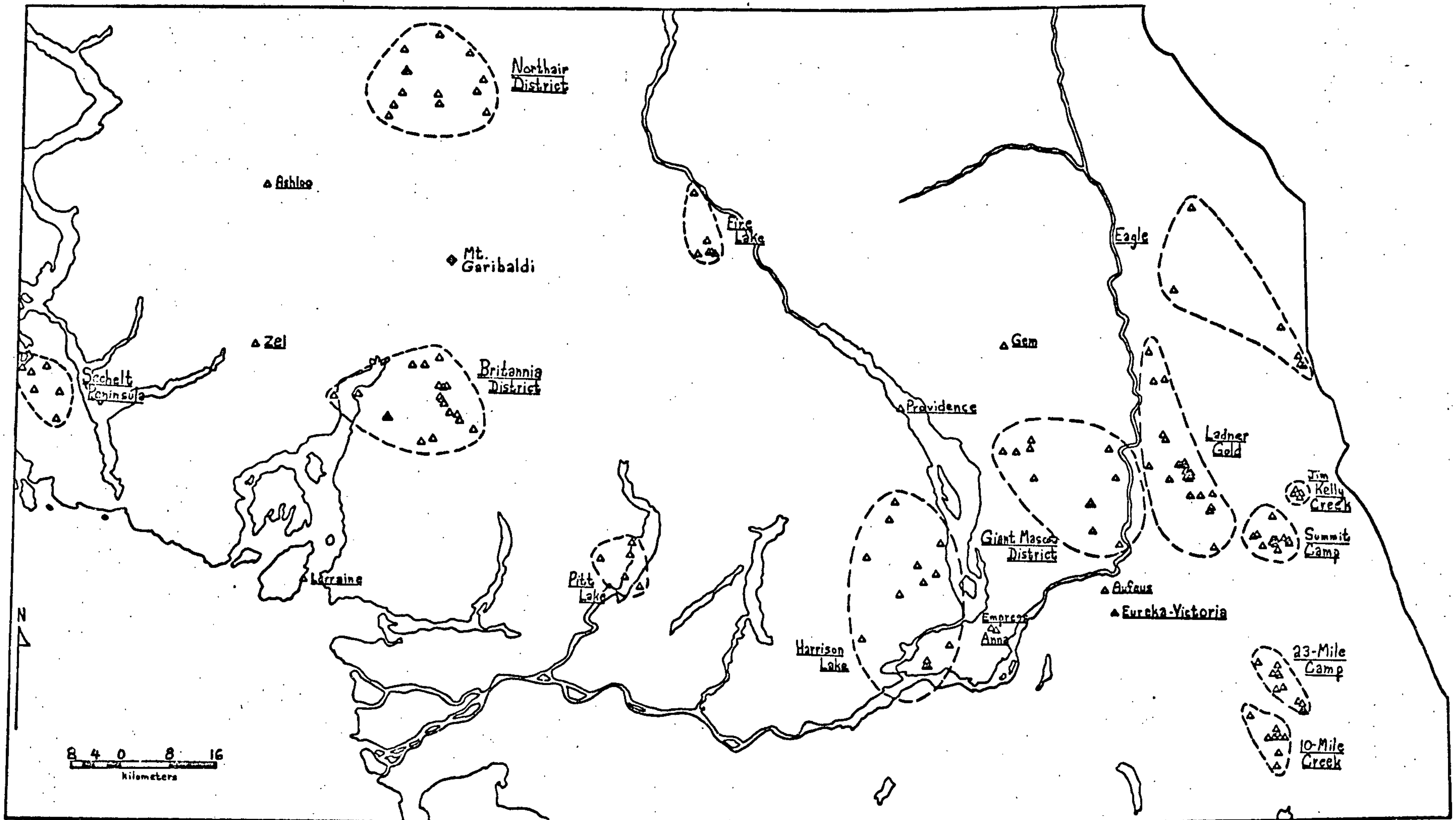

Figure 3-1. Principal areas of mineral occurrences, Vancouver-Hope area.

Table 3-2. ABBREVIATIONS AND SYMBOLS USED IN DEPOSIT DESCRIPTIONS

ac	actinolite
ak	ankerite
am	amphibole
an	anhydrite
ap	arsenopyrite
ar	argentite
at	apatite
Au	native gold
az	azurite
ba	barite
Bi	native bismuth
bo	bornite
ca	calcite
cb	carbonate
cc	chalcocite
cl	chlorite
cp	chalcopyrite
cu	cuprite
Cu	native copper
cv	covellite
en	enargite
ep	epidote
fd	feldspar
fm	ferrimolybdite
ga	galena
gt	garnet
gy	gypsum
hb	hornblende
he	hematite
jm	jamesonite
ko	kaolinite
mg	magnetite
ml	malachite
Mn	manganese stain
mo	molybdenite
Mo	molybdenum
mr	marcasite
po	pyrrhotite
pr	pyrolusite
pt	pentlandite
py	pyrite
qz	quartz
sb	stibnite
sc	specularite
sd	siderite
sh	scheelite
sl	sphalerite
sn	spinel
sp	sulfides
ss	sericite
st	strontianite
tt	tetrahedrite
to	tourmaline
ur	uraninite
wo	wollastonite
( )	minor amount
*	producing deposit
+	high dip angle
-	low dip angle
frags	fragments

CLASSIFICATION

An ideal classification scheme for a metallogenic study concisely describes each deposit in genetic terms. Studies on a larger scale than this one (e.g., Sutherland Brown, *et al.*, 1971) generally deal only with producing deposits or important occurrences which have been described in sufficient detail to be classified genetically with reasonable certainty. However, this study deals mainly with occurrences about which little is known; only three can be called major producing deposits. Restrictions imposed by insufficient data have resulted in deposit classifications which are broadly defined and do not necessarily imply a specific origin. The classification scheme used in this study is outlined below.

Magmatic

Magmatic deposits are identified by the presence of massive and/or disseminated copper and nickel sulfides (commonly chalcopyrite and pyrrhotite, respectively) in ultramafic host rocks. Sulfides are assumed to have been derived from the magma; therefore their age and genesis are similar to that of the host rock.

Porphyry

Porphyry deposits are low-grade accumulations of copper and/or molybdenum sulfides genetically related to their intermediate to felsic intrusive host rocks, but they may also occur in nearby country rocks. Metals such as silver, gold, zinc and iron are uncommonly present in minor amounts. Sulfides (and rare iron oxides) occur as disseminations, in quartz vein stockworks, or in intrusive and/or pipe-like breccia bodies.

Conventional definitions of porphyry deposits (*cf.* Sutherland Brown and Cathro, 1976) describe mineralization associated with porphyritic granitic rocks which were emplaced relatively near the surface; sulfides formed during the late stages of emplacement and consolidation of the host intrusion.

Porphyry deposits of the present study include "conventional" porphyries as outlined above and occurrences of sulfides in coarse, even-grained granitic rocks which probably formed at greater depths than porphyritic granitic rocks. Despite the difference in character of host plutonic rocks, the genetic link between sulfide deposition and late-stage plutonic events is probably the same for porphyries in coarse, even-grained and porphyritic, fine-grained host rocks.

Skarn

Skarn deposits are characterized by calc-silicate mineral assemblages produced by contact metasomatism mainly in calcareous rocks near intrusive bodies. Mineral assemblages are diverse and vary considerably within and among deposits. Chalcopyrite, magnetite and pyrrhotite are the most commonly reported minerals of economic interest; garnet, epidote and calcite are the most commonly recognized gangue minerals.

Volcanogenic

Volcanogenic deposits in the study area were produced by submarine exhalative activity which closely followed eruption of acidic pyroclastic rocks. Base metal mineralization is dominated by pyrite, chalcopyrite, and/or sphalerite and galena; gold and silver enrichments are not uncommon. Quartz is the dominant gangue mineral, but barite is common; large concentrations of anhydrite may occur near sulfides, but rarely within sulfide bodies.

Since most potential host rocks in the study area have undergone deformation, recognition of volcanogenic deposits is difficult, and this may account for the identification of only two deposits to date. Recent developments of the volcanogenic hypothesis (cf. Hodgson and Lydon, 1977) make it clear that potential environments not requiring pyroclastic volcanism[1] also exist, but detailed information necessary to recognize such environments is seldom available.

Vein

Classification of a deposit as a vein is primarily based on the tabular, commonly discordant nature of the occurrence; an epigenetic, hydrothermal origin is assumed for all veins, although it is possible that some tabular syngenetic deposits have been classified as veins. Since veins commonly are integral constituents of most deposit types, they are described as "veins" only when they appear to be isolated and/or unrelated to mineralization which may be classified more specifically. Most vein deposits are valued for their precious metal content, but many other metals can be present; quartz is the most common gangue mineral.

Shear

Shear deposits occur in shear zones[2] as small bodies or disseminations of sulfides that are not accompanied by gangue minerals such as quartz and calcite. Pyrite, chalcopyrite, sphalerite and galena are the most commonly reported sulfides.

This category may overlap somewhat with veins confined to shear zones, but veins are distinguished by being either (1) massive, well-defined, continuous bodies and/or (2) small, discontinuous bodies with a considerable amount of gangue minerals. The distinction between vein and shear deposits is made because the absence of gangue minerals in shear deposits is suggestive of an origin different to that of veins. Whereas veins are commonly deposited from structurally-controlled hydrothermal solutions, the origin of

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[1]The ocean-floor rifting environment is a well-known setting for volcanogenic deposits, but does not occur in the study area.

[2]The term "shear" is imprecise, as it does not always imply that shear displacement has taken place. A preferred expression is "a zone of intense foliation," but the term shear zone is retained since it appears abundantly in the literature.

shear deposits might be linked to development of the shear zone as a contemporaneous feature. Development of intense foliation and recrystallization in host rocks during the formation of a shear zone might cause migration of sparce sulfide components from surrounding rocks into the shear zone where they might accumulate as coarse disseminations or aggregates.

Disseminated and Massive

These categories are used as descriptive terms for sulfide accumulations which cannot be classified as any of the foregoing deposit types due to inadequate descriptive geological data. Therefore, deposits in these categories probably include representatives of other deposit types whose mineralization is disseminated or massive in character.

MAJOR MINES AND RELATED OCCURRENCES

Britannia

Although only two volcanogenic deposits are reported in the study area, the 53 million tons of ore produced from Britannia make this type of occurrence the most important of all. The other volcanogenic deposit, Seneca (HSW-13), produced 287 tons in comparison.

Intense deformation and alteration superimposed on complex stratigraphy make interpretation of the geology of the Britannia area difficult. Although recent ideas on the origin of Britannia consider the deposit to be syngenetic, most published reports discuss an epigenetic origin.

Geologic Setting and Early Interpretations

Orebodies at Britannia are on both limbs and the crest of a major anticline in a large northwest-trending shear zone in a pendant of Lower Cretaceous Gambier Group rocks in the Coast Plutonic Belt. This zone of shear movement is the locus of folding, faulting and the development of intense schistosity and related alteration and recrystallization during shear deformation. Because most sulfide veins parallel foliations in the shear zone, early workers interpreted them as introduced along foliations. Local bedded sulfides were interpreted as replaced sedimentary beds, and the position of ore structurally below slate and dacite dike "hoods" was interpreted as a result of ore solutions being ponded below impermeable barriers. Brecciation, folding, shearing and silicification were looked upon as ground preparations for ore solutions. The occurrence of bedded zinc-rich sulfides in sedimentary rocks and copper-rich sulfides in volcanic rocks was interpreted as a reflection of host rock preference, although an explanation of this preference was not presented.

Schofield (1918, 1922, 1926) and James (1929) attributed the origin of orebodies to hydrothermal solutions related to intrusion of surrounding plutonic rocks. On the basis of temperature of formation of mineral assemblages, Irvine (1946) suggested that plutonic rocks might not be the source of mineralization, but did not propose an alternate source.

Current Interpretations

In 1969 and 1970, world-wide interest in the volcanogenic model stimulated reinterpretation of many deposits hosted by acidic volcanic rocks, and Britannia was no exception. Sutherland Brown and Robinson (1970) described the relationship between ore deposits and stratigraphy at Britannia, and concluded that the ore was volcanogenic in origin, dominated by the Keiko (stringer) variety. A detailed study by many Anaconda geologists who worked at the mine (Payne, *et al.*, 1974) is the basis for the following discussion.

Orebodies are in a dacitic volcanic center dominated by a complex sequence of volcanic flows and pyroclastic rocks. During hiatuses in dacitic volcanism, andesitic sediments were supplied from nearby centers.

TABLE 3-3. CHARACTERISTICS OF DEPOSITS IN THE BRITANNIA DISTRICT

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Gangue	Mineralization
G-3* Britannia	volcanogenic	Gambier Group	dacitic volcanic rocks	massive bodies	an,ba,qz,gy	sl,py,cp (ga,ar,po)
			andesitic tuff and sedimentary rocks	stringers	qz,ca,ba	cp,py (tt,ga,sl)
G-4 Bank of Vancouver	porphyry	Coast Plutonic Complex	quartz diorite to quartz monzonite	breccia pipe with veins, stringers, and mineralized matrix	he,mg,cl,cb,qz	cp,py (mo,sl)
G-6 McVicar	shear (volcanogenic?)	Gambier Group	quartz/sericite schist (well-foliated greenstone tuff)	veinlets and disseminations	qz	py,cp,sl (ga)
				bedded sulfides		ga,sl
G-17 Venus	porphyry		quartz porphyry	fracture fillings		cp,mo
G-21 Roy Group	disseminated	Gambier Group	altered, silicified, porphyritic, tuffaceous, andesitic greenstone	joints	qz,cl	py (cp)
G-22 Ray Creek	shear	Gambier Group	green tuffaceous schist	lenses	qz	py,cp
				shears		cp (sl)
G-31 Irish Molly	porphyry		recrystallized aplite dike?	lenses; bunches	qz	py,cp
G-32 Bulliondale	porphyry		acid porphyritic dike and limestone			py,cp
G-43 Indian River Copper	shear	Gambier Group	volcanic rocks	"replacements"		cp,sl
G-62 Horseshoe	shear	Gambier Group	schist	lenses	qz	py,po (cp)
G-77 Roy	massive	Gambier Group	andesitic greenstone porphyry	massive "vein"	qz	cp,py (sl)
G-85 Caledonia	disseminated	Gambier Group	schist			py,cp
G-86 ABC Group	shear	Gambier Group	well-foliated, schistose greenstone	disseminations		py,cp
G-89 SUN	porphyry			breccia pipe		py,cp
G-124 Christina	shear	Gambier Group	partly schistose greenstone and chlorite schist	"replacements" paralleling schistosity		py,cp,sl (ga)
G-125 Dal No.1	disseminated	Gambier Group	fissile tuff and schist			cp,sl,py
G-126 McKinnon Group	disseminated	Gambier Group	schist	disseminations		py,cp (sl)
G-133 London	porphyry	Coast Plutonic Complex (Indian River Intrusions)	quartz diorite	veinlets in joints	qz	py,cp,sl,mo
G-152 Cash	shear	Gambier Group	chlorite/sericite schist	silicified shear zones with veinlets	qz	py

During one hiatus, sulfides and related bodies of anhydrite were formed. Massive, bedded, zinc-rich orebodies occur in andesitic sedimentary rocks above or at the contact with a particular unit of coarse dacitic tuff below the sedimentary section. This coarse dacitic tuff and the sedimentary rocks at the upper contact are host to copper and zinc sulfides in stringers and massive bodies.

Orebodies were deformed during a major episode of deformation which produced the shear zone and related foliation. Most orebody contacts are along or near late major northwest-southeast faults. An hypothesis based on removal of cumulative right-lateral movement of some 8,000 feet along these faults allows a reconstruction of sulfides into two original orebodies. If this is correct, a large portion of massive lead-zinc-rich ore may have been eroded; this hypothesis explains why stringer-type copper sulfides are more abundant than normally would be expected to be associated with the present amount of massive zinc and copper-zinc ore.

Sulfide Occurrences Outside the Britannia Shear Zone (Table 3-3)

Descriptions of mineral occurrences in the Britannia pendant are reminiscent of early reports on the Britannia orebodies. Two deposits report massive mineralization: G-77 is a massive chalcopyrite body with less abundant sphalerite; G-6 (McVicar) contains massive, bedded, sphalerite-rich ore with galena and stringer-type copper-zinc sulfides. Other deposits hosted by schistose, andesitic, volcanic rocks commonly are described as disseminations, lenses and veinlets parallel to schistose fabrics; sulfides include pyrite, chalcopyrite, sphalerite and rare galena.

Figure 2-1 shows the location of these deposits near a poorly-defined shear zone sub-parallel to and east of the Britannia shear zone. Host rocks are undeformed dacitic flows and pyroclastic units, many of which contain abundant disseminated pyrite (J. G. Payne, personal communication, 1978). James, 1929, considered the absence of barite, anhydrite and the "Britannia Sills" (dacite dikes) in this area to be significant indications of unfavorable conditions for mineralization. However, barite is not abundant at Britannia, anhydrite is leached readily from surface rocks, and the "Britannia Sills" are now believed to be post-ore. The most reasonable hypothesis regarding the origin of these deposits is that they are the same age and type as the Britannia orebodies.

Porphyry deposits in the Britannia district are either associated with the "Indian River intrusions" near the eastern shear zone (G-31,32,133), or near the Britannia shear zone, just outside the limits of the pendant (G-4,17,89). The Indian River intrusions are believed to be late acidic phases of the Coast Plutonic Complex which intrude pendant rocks (James, 1929). Copper and local molybdenum sulfides in these porphyries are sparce. More abundant mineralization is located in intrusive breccia pipes in plutonic rocks (G-4,89) at the southeastern end of the Britannia shear zone.[3] Age of mineralization corresponds to late stage activity of intruding plutons, in Upper Cretaceous time.

Northair

High-grade vein mineralization at Northair was discovered in 1969; production began in 1976, and continues to make this mine the only operating one in the study area. Reserves as of May, 1977, are estimated at 330,637 tons, averaging 0.4 ounces/ton gold, 4.6 ounces/ton silver, 2.7 percent lead and 4.0 percent zinc.

Description

Sulfides occur in three one-to-forty-foot-wide, northwesterly-trending,

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[3]Veins of massive chalcopyrite also occur in plutonic rocks in this vicinity (J. G. Payne, personal communication, 1978), but descriptions of specific localities are not available.

vertical, more-or-less tabular sheets which appear to be offset by northerly-trending, sub-vertical faults (refer to Figure 3-2). Vein minerals include pyrite, sphalerite and galena, and minor amounts of chalcopyrite, native gold, pyrrhotite and various silver minerals (argentite, tetrahedrite, stromeyerite) in a quartz-carbonate gangue. Quartz and calcite exhibit deformation textures; sulfides and gangue in part appear to be recrystallized.[4] No hydrothermal alteration related to the vein has been recognized.

The three sulfide bodies, called (northwest to southeast) the Discovery, Warman and Manifold Zones, are distinguished from each other by metal ratios, metal contents and textures, summarized in Table 3-4. Enclosing rocks are considered equivalent to the Lower Cretaceous Gambier Group, although this correlation is tenuous, as discussed in Chapter Two. The southern portion of the pendant contains a 5,000-meter section of homoclinal, northerly-trending, vertical or steeply east dipping, andesitic to rhyolitic, fragmental volcanic rocks including coarse agglomerates and fine-grained tuffs (Miller, et al., 1978). Where present, schistosity and faults commonly are sub-parallel to bedding in volcanic rocks, so that northwesterly-trending veins cross-cut the structural grain of the host rock.

A K/Ar date of 124 ± 4 Ma was obtained from hornblende in an intrusive rock believed to be a feeder for surrounding hornblendic crystal tuffs stratigraphically below mineralized agglomerates (J. H. Miller, personal communication, 1977). However, the intrusion may post-date tuffaceous rocks. A whole rock K/Ar date of 74 Ma on foliated greenstone adjacent to sulfide bodies (Little, 1974) indicates that greenschist metamorphism of pendant rocks, intrusion of plutons, and/or vein emplacement might have occurred at

[4] Strained cleavage in calcite and undulatory extinction in quartz were noted by the writer; sulfides and gangue minerals form an equilibrium texture with common 120° grain boundaries.

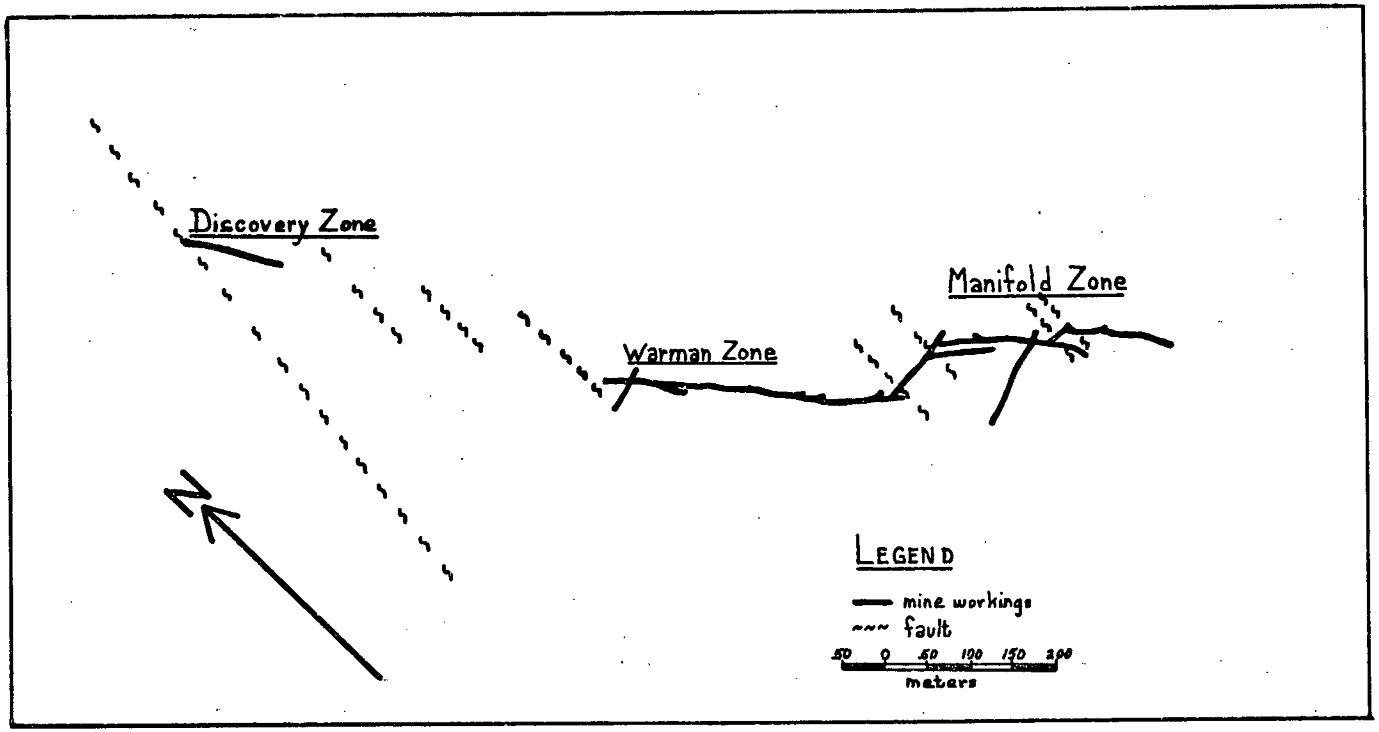

Figure 3-2. Relative positions of the three main mineralized zones and faults at Northair Mines (after Dickson and McLeod, 1975, and Miller, et al., 1978).

TABLE 3-4. CHARACTERISTICS OF THE NORTHAIR SULFIDE BODIES

	Cu[1]	Pb[1]	Zn[1]	Au[1]	Ag[1]	Texture[2]
Discovery Zone	.55	5.43%	6.58%	.10 oz/T	1.18 oz/T	massive (locally banded) and veinlets
Warman Zone	.24	1.45%	2.39%	.68 oz/T	.85 oz/T	massive, disseminated and veins
Manifold Zone	.07	.28%	.57%	.28 oz/T	14.48 oz/T	veins and disseminated (considerable quartz and carbonate gangue)

[1]from Manifold, 1976

[2]from Miller, *et al.*, 1978

this time (or earlier).

Genesis

As schistosity and faulting are parallel to the large-scale outline of the pendant, they are believed to be results of the intrusion of surrounding plutonic rocks, and therefore mineralization which is cut by these structures pre-dates intrusion in the vicinity (M. P. Dickson, personal communication, 1975). Although Northair is a tabular body which geometrically resembles a vein, metal and host rock associations are suggestive of a volcanogenic origin. Two major factors must be clarified before the volcanogenic hypothesis of origin can be applied with certainty.

1) Small-scale deformation of the vein should be demonstrated to be equivalent (i.e., parallel) to deformation of the host rock.

2) If sulfides (and gangue?) have not been transported far, they should be spatially related to a stratigraphic-time horizon in the volcanic host rock. If massive portions of the vein are original syngenetic accumulations (Miller, et al., 1978), transportation could not have been great.

If sulfides at Northair are not stratabound, but cross-cutting, as suggested by Manifold (1976), an epigenetic origin must be envisioned. However, if sulfide mineralization was syn- or post-deformation synchronous with intrusion of the Coast Plutonic Complex, vein-forming hydrothermal solutions would be expected to follow structural trends of the host rock.[5] Since mineralization cross-cuts foliations, an epigenetic vein would have to have been emplaced after deposition of the host rock and before deformation. If host rocks are Lower Cretaceous, the available time interval for epigenetic mineralization is minimal, since Coast Plutonic Complex K/Ar dates and Gambier Group deposition overlap in the upper Lower Cretaceous.

[5] The conclusion that post-deformational hydrothermal fluids would follow pre-existing planes of weakness is based on the knowledge that basalt dikes in the mine area that feed overlying Quaternary flows do follow schistosity.

It appears that if one is to consider epigenetic hydrothermal mineralization, the age of the host rock must be examined more closely. If host rocks are of the Upper Triassic Pioneer Formation, vein mineralization is more easily reconciled with the available data.

Two additional points of interest regarding a supposed volcanogenic origin are the following:

1) Carbonate is not usually reported in great quantities from volcanogenic deposits, and yet it accounts for half the gangue at Northair. Perhaps the carbonate is not a by-product of mineralization, but represents a calcareous horizon in the host rock that may have helped localize sulfides (Miller, et al., 1978).

2) An environment distal from the source vent is suggested by lack of stringer zones and very low copper values. This environment is considerably different from that of other volcanogenic deposits in the study area (Britannia, G-3; Seneca, HSW-13) which are copper-rich with abundant stringer mineralization.

It is not possible at this time to do much more than speculate on the origin of mineralization at Northair. Available information suggests to the writer that the deposit is a vein, but the origin of that vein is questionable, as is the presence of syngenetic mineralization.[6] Sulfides were probably originally volcanogenic accumulations, but until more data are presented to clarify certain relationships discussed above, the deposit cannot be categorized as volcanogenic in nature.

Formation of vein mineralization, if epigenetic or remobilized syngenetic, would have occurred in Upper Cretaceous time during intrusion of surrounding plutons. If sulfides are deformed syngenetic deposits, they would have formed in Lower Cretaceous time, if host rocks belong to the Gambier Group.

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[6] Unpublished data indicating the presence of disseminated sulfides in bedded carbonate and the fact that portions of the deposit consist of multiple veins suggest to current investigators that the deposits cannot be considered a vein, but a distal volcanogenic deposit (Sinclair, personal communication, 1978).

Other Deposits in the Northair District (Table 3-5)

Occurrences in the Northair District are hosted by plutonic and metavolcanic rocks; the latter are contained in two northerly-trending pendants of Gambier (?) Group rocks surrounded by intrusive rocks (Figure 2-1). Veins, disseminations, shears, skarns and porphyries are present.

The four deposits in the western or Callaghan Creek pendant (J-45,51, 151,152) are mineralogically similar to Northair, and therefore might be related genetically. Disseminated lead-zinc-copper mineralization in stringers and disseminations is accompanied uncommonly by quartz-carbonate gangue and may be localized along shear zones in andesitic greenstone hosts. One deposit (J-51, Blue Jack or Silver Tunnel) is possibly syngenetic, and has been deformed (Woodsworth, et al., 1977). Definition of a mineralizing episode for the remaining deposits is not feasible; both Lower Cretaceous deposition of host rocks and Upper Cretaceous intrusion of nearby plutons are potential mineralizing events.

Mineralization in and around the eastern pendant differs considerably from that of the Northair pendant. Although both pendants are proposed to be of the same formation, the eastern pendant contains very little known lead-zinc mineralization. Aside from one galena and barite vein in greenstone (J-150), deposits in the eastern pendant are either skarns in pendant rocks (J-42,67), or porphyries in intrusions (J-49,50,134). Skarn and porphyry deposits formed during intrusion of plutonic rocks in Upper Cretaceous time.

Giant Mascot

Giant Mascot (also Pride of Emory, Pacific Nickel) is the only occurrence of magmatic nickel and copper in the area which ever produced; 6.0 million tons of ore were mined.

TABLE 3-5. CHARACTERISTICS OF DEPOSITS IN THE NORTHAIR DISTRICT

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Attitude	Gangue	Mineralization
J-42 London	skarn	Coast Plutonic Complex	quartz/sericite schist (well-foliated granodiorite)			ca	cp,ml,py
		Gambier(?)Group	metabasalt	skarn zone		ep,mg,ca,qz	
J-45* Astra, Cambria	disseminated	Gambier(?)Group	andesite; diorite	stringers	N35W,65SW	qz,cb	ga,sl,cp,py
J-49 Azure	porphyry	Coast Plutonic Complex	quartz/sericite schist (well-foliated granodiorite)	stringers and lenses		qz	cp,py (ml,az)
J-50 Elk	porphyry	Coast Plutonic Complex	granite	fractures and shears		ss,cl,qz	ml,cp,mo,py
J-51* Blue Jack	shear	Gambier(?)Group	muscovite/chlorite schist	lenses, streaks and disseminations in shear zone	N-S,65W	wall rock (qz,ca)	ga,sl,py,cp,Au,tt
J-67 Fitzsimmons	skarn					ep,cb,gt	py,sl,cp (ga,mg)
J-130* Northair	vein	Gambier(?)Group	pyroclastic andesite	vein	N55W, + N	qz,cb	py,ga,sl,cp
J-131 CI,JE	vein	Coast Plutonic Complex (?)		vein		qz	cp
J-132 CI,JE	disseminated	Coast Plutonic Complex		disseminations			cp,ml
J-134 RM	porphyry		meta-diorite	shear zone	NW		cp,py
J-150 (occurrence)	vein	Gambier(?)Group	greenstone	vein		ba	ga
J-151 Kay	disseminated	Gambier(?)Group	andesitic volcanic rocks	veinlets and shear zones			ga,sl (cp)
J-152 TMC No.1	disseminated	Gambier(?)Group	andesite; minor quartz diorite	small fractures			Cu,Ag,Zn

Nature and Origin of Ultramafic Rocks

The Giant Mascot Ultramafite is a unique elliptical, crudely-zoned body (Figure 3-3) which does not fit into most existing classification schemes (cf. Naldrett and Cabri, 1976). The dominance of orthopyroxene in ultramafic and noritic rocks and the presence of magmatic sulfides are the major features which distinguish the Giant Mascot Ultramafite from "Alaskan-type" zoned ultramafic intrusions.

Several steeply-dipping, pipe-like cores of peridotite and less common dunite are surrounded by substantial amounts of pyroxenite (hornblendic and bronzitic); erratic zones of hornblendite occur along the periphery of the main ultramafic body. Norite and diorite are the major feldspathic intrusive rocks surrounding the ultramafic body.

Similar pyroxenes in ultramafic and dioritic rocks have led authors (Cockfield and Walker, 1933; Horwood, 1936; Aho, 1956; and Peach, in Clark, 1969) to the conclusion that differentiation of an orthopyroxene-rich magma produced progressively less mafic intrusive phases. K/Ar dates (McLeod, et al., 1976) indicate that ultramafic rocks (119-95 Ma) cooled shortly before dioritic phases (79-89 Ma). Cumulate textures suggested to McLeod (1975) that the original differentiating magma was crudely stratiform before re-emplacement as a "crystal mush."

Mineralization

Pyrite, pentlandite, chalcopyrite, pyrrhotite and magnetite occur in three types of orebodies: zoned, massive and vein-like. Zoned orebodies of disseminated sulfides occur within the pipe structures referred to above. The presence of sulfides is a function of rock type, as dunite and peridotite cores commonly contain sulfides, pyroxenites less commonly so, and hornblendite rarely. Norite contains rare disseminated sulfides. Sulfide and

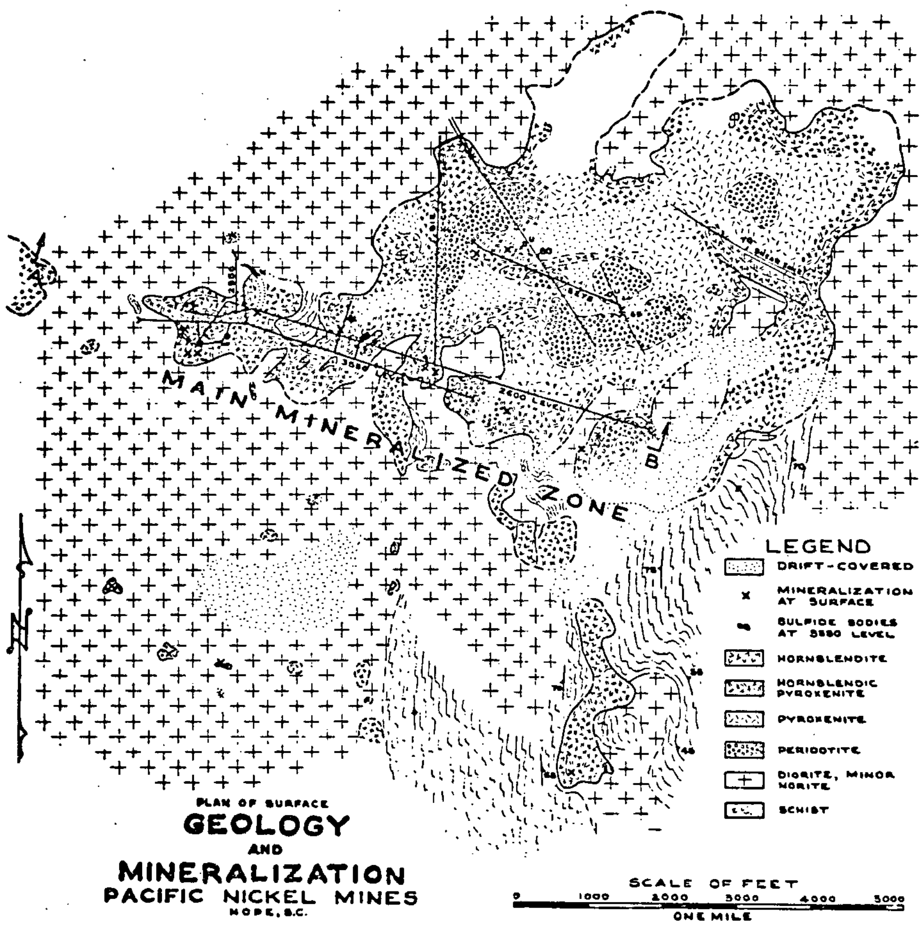

Figure 3-3. Surface geology of the Giant Mascot Ultramafite (from Aho, 1956).

rock type relationships are not consistent; a sulfide-rich rock type in one orebody may be barren in another. Nickel to copper ratios are highest in the cores of zoned orebodies, decreasing outwards as total sulfide content decreases.

Massive orebodies are similar mineralogically to zoned ones, but are irregular in form, and commonly show evidence of movement or remobilization through brecciation, large-scale protoclastic textures, or flow-banding. Sharp contacts are characteristic of massive orebodies, but some grade into zoned orebodies.

Vein-like sulfides with lower nickel to copper ratios than either zoned or massive orebodies occur in all rock types, but are economic only where enriching larger orebodies. These veins can probably be attributed to late-stage mobilization of existing sulfide bodies.

The origin of mineralization at Giant Mascot remains as much of a dilema as the origin of the ultramafic host rocks. Cockfield and Walker (1933) favored a hydrothermal origin for the sulfide bodies; McTaggart (1971) favored a metasomatic origin for the pipes by fracture-controlled fluids, and Aho (1956) proposed high-temperature metasomatic and magmatic origins for pipe and massive orebodies, respectively. Cairnes (1924), Horwood (1936) and McLeod (1975) favored a magmatic origin involving segregation and subsequent injection of sulfides. McLeod (1975) supported his view by demonstrating that pyroxene pairs from assorted rock types in the ultramafic body equilibrated at a mean minimum temperature of 990°C.

Although detailed knowledge of the processes involved is lacking, a complex magmatic origin is accepted here for the ultramafic body and its contained sulfides. Age of sulfide formation, 108 ± 4 Ma (McLeod, 1975), corresponds to that of mineralized hornblendite in one of the orebodies.[7]

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[7] It is important to consider the significance of this date (and others in

Occurrences Outside the Giant Mascot Ultramafite (Table 3-6)

As mentioned in Chapter Two, the Giant Mascot Ultramafite is spatially associated with a belt of ultramafic rocks near the northern extension of the Shuksan Thrust. The largest ultramafic body is on Old Settler Mountain, in the southern portion of the belt. Described by Lowes (1972) as a typical alpine-type ultramafite, it is mainly dunite and contains no sulfides. Smaller bodies north of Old Settler Mountain, in the Cogburn Creek area, are similar to Giant Mascot (HNW-38,39,40,41,42). Pyroxenite and hornblende-pyroxenite, mineralized sparingly by massive and disseminated pyrite, pyrrhotite, chalcopyrite and rare pentlandite, are closely associated with Spuzzum diorite in these deposits. Orthopyroxene is of secondary abundance compared to clinopyroxene in these occurrences. Similarities to Giant Mascot suggest that mineralization at Cogburn Creek was contemporaneous with that at Giant Mascot.

Other magmatic deposits commonly are associated spatially with major faults, implying an origin linked to movement along these deep-seated crustal breaks. HSW-5 and HNW-52 are near the Hope Fault, and outside the Giant Mascot District, HNW-34, HSW-118 and HSW-125 are near the Hozameen Fault. Mineralization is presumed to have occurred during faulting when access to mantle (?) sources was obtained.

MINING CAMPS WITHOUT MAJOR MINES

Camps or districts discussed in this section stand out as areas of relatively high concentrations of mineral prospects. Regardless of production, if any, they have generally boasted of enough mineral occurrences

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the Spuzzum Plutonic Belt) in light of the fact that high pressure and temperature metamorphism discussed in Chapter Two might have affected argon retention in these rocks. Thus the reported age of the Giant Mascot Ultramafite and its sulfides might be younger than the actual age which might pre-date metamorphism and/or intrusion of the Spuzzum and Scuzzy plutons.

TABLE 3-6. CHARACTERISTICS OF DEPOSITS IN THE GIANT MASCOT DISTRICT

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Gangue	Mineralization
HSW-4* Giant Mascot	magmatic	Giant Mascot Ultramafite	peridotite; hornblende pyroxenite ; dunite	pipe-like bodies		massive; disseminated po,pt,cp,py
HSW-5 Bea	magmatic		ultramafic			po,py,cp
HSW-111 Swede	magmatic		pyroxenite; peridotite			disseminated po,cp,py
HNW-38 AL	magmatic	Spuzzum Pluton	fractured and silicified mafic-rich rocks in quartz diorite	bands and lenses		massive py,po (cp,pt)
HNW-39 occurrence	magmatic		hornblende pyroxenite			pervasive po,cp,py
HNW-40 occurrence	magmatic		pyroxenite			disseminated cp
HNW-41 occurrence	magmatic		hornblende pyroxenite			
HNW-42 occurrence	magmatic		amphibolite (?)			massive; disseminated py (po,cp)
			pyroxenite			disseminated cp,po
HNW-45 Victor	magmatic		amphibolite			disseminated py,po,cp
		Spuzzum Pluton	meta-quartz diorite	near gabbro/pyroxenite contact		minor
			peridotite (?)			disseminated po,cp
HNW-52 Citation	magmatic		schist; amphibolite			Cu,Ni,Zn

to have attracted considerable exploration interest. Locations of all camps are shown in Figure 3-1.

Eagle Belt (Table 3-7)

Two distinct types of mineral occurrences are present in the Eagle Belt. Copper, zinc and lead sulfides occur as disseminations (HNW-22,23) and in a vein (HNW-24). Molybdenum and copper sulfides occur in porphyry deposits in breccia bodies (HNW-28,54) and a dike (HNW-31). Assuming the breccia bodies and dike are related to late stages of plutonism in the Eagle Complex, deposition of sulfides is contemporaneous with the formation of this complex in Jurassic or Lower Cretaceous time. The age of copper-zinc-lead deposits is more difficult to determine, as the mineral assemblage is not characteristic of sulfide deposits associated with plutonic rocks, and the nature of non-plutonic rocks in the vicinity is uncertain.

Summit Camp (Table 3-8)

Fault-controlled mineralization of the Summit Camp on Treasure Mountain has been explored and worked intermittently since 1894 when the Eureka claim was located. Veins and stringer zones from one inch to five feet wide contain pyrite, sphalerite, and galena, with minor amounts of tetrahedrite, pyrrhotite, chalcopyrite, stibnite, quartz, calcite and siderite. The most common occurrences are thin sulfide veinlets, with or without gangue, that occupy a much wider fracture zone composed of altered country rock with, perhaps, some gouge.

Fault zones are nearly perpendicular to bedding, and sulfides are found erratically along them. Ten of the twelve deposits in the Summit Camp occur in Lower and Middle Jurassic Ladner Group volcanic and sedimentary rocks. The remaining two are in Lower Cretaceous Pasayten sedimentary rocks. Distribution between these host rocks appears to be a function of the amount

TABLE 3-7. CHARACTERISTICS OF DEPOSITS IN THE EAGLE COMPLEX

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Width	Attitude	Gangue	Mineralization
HNW-22 Mag Group	disseminated	Eagle Complex	intrusive breccia	fractures;veins				py,cp,sl
			altered porphyry	disseminations				py,cp,sl
HNW-23 Ly,Ford, Snow,Dora	disseminated	Eagle Complex	altered porphyry (quartz monzonite or quartz diorite)	zone of disseminations	150'	NW,50NE		py,sl,ga (cp)
HNW-24 Coldwater	vein	Eagle Complex	altered quartz monzonite limestone and rhyolite near granodiorite	vein		N40E,70NW	qz (cb)	py,ga,sl,tt (cp)
				fractures			qz	sl,ga
HNW-28 JM,SEC	porphyry	Eagle Complex	breccia	pipe (?)				mo (cp)
HNW-31 Gossan	porphyry	Eagle Complex	granitic, porphyritic dike intruding granodiorite	alteration halo around dike with stringers			qz	py (cp,mo)
HNW-54 Mod Bar	porphyry	Eagle Complex	rhyodacite porphyry	altered area near breccia pipe with phyllic alteration			(qz)	py,cp,mo,cu,en,cc

TABLE 3-8. CHARACTERISTICS OF DEPOSITS IN THE SUMMIT CAMP

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Width	Attitude	Gangue	Mineralization
HSW-16* Silver Chief	vein	Pasayten Group	argillite, arkose and conglomerate	fault zone	1"-20'	N50E,65SE N70E,65SE	qz,cb,sd	sl,ga,py,cp,tt (Mn)
HSW-18* Eureka	vein	Ladner Group	argillite, breccia and conglomerate	vein along fault	4"-12"	N45E	qz,ca	ga,sl,cp
				vein along dike	18"	N70E		
HSW-19 Southern No. 8 Fr.	vein	Ladner Group	agglomerate and black argillite	vein	4"-6"	N20E, +E	cb,qz	ga,sl,cp,py
				bedded quartz veinlets	up to 19"	N20E,50SE	qz	sb
HSW-20 Bluebell	vein	Ladner Group	argillite, breccia and conglomerate	vein	1"-1'	SW,N	qz,gouge	sl,ga,py
				fracture zone		WSW	qz	(sp,Mn)
HSW-21 Queen Bess	vein	Ladner Group		stringers	1'-3'	SW,NW	qz	sl,ga,py
				vein along fault	6"	N65E, +		sp,py (Mn)
			massive breccia and agglomerate; tuff and argillite	contacts of dike				py,sl,ga
HSW-22 Indiana	vein	Ladner Group	tuff, breccia and argillite	stringers in 20' zone	1"-6"	N75E,70SE	gouge, rock frags (qz,cb)	ga,sl,py
					17"	N60W		po,sp
HSW-23 Summit	vein	Ladner Group	contact of porphyry and quartzite	vein	6'-8'			ga
			massive agglomerate, tuff and argillite	stringers	15"	N70E,70SE	rock frags,?	?
HSW-45 U.S. Rambler	shear	Ladner Group		"seam"	2'-4'	N33E	rock frags	py,ga,sl
HSW-46 Blackjack	shear	Ladner Group		"seam"	10"-12"		rock frags	py,ga,sl
			coarse black dike	dike walls	20'			sl,ga
HSW-47 Hall's Group	shear	Ladner Group	quartzite with pyritic bands	rusty bed				py
				bedded gouge seam	9"			py,sl
HSW-66 Rainy	shear	Pasayten Group	argillite and conglomerate	shears and fractures				sl,po,py,cp
HSW-85 Morning Star	vein	Ladner Group	tuff and massive andesite	vein	3"-4"	E-W,40S		
				stringers in fracture zone	5'	N60E	qz,rock frags	ga,tt,cp

of faulting, since of the five recognized faults in the camp, only one has been traced into the Pasayten Group.

Two reports of host rock preference from different deposits in this camp conflict as to whether argillite is associated with rich or poor mineralization. Host rock control, therefore, is assumed to be minimal. Rock type hosts include quartzite, agglomerate, tuff, breccia, conglomerate, arkose and argillite.

Old reports commonly attribute the source of sulfides to a porphyritic dike which intrudes the Treasure Mountain fault zone and commonly separates mineralized zones into hanging- and footwall portions. However, the main relationship between this dike and mineralization is that both intruded the weak fault zone; dike and sulfides commonly are independent of each other.

Sulfides occur in faults that offset the Chuwanten, defining their age as post-86 Ma. The only known post-86 Ma events nearby that might be responsible for mineralization are intrusion of the Needle Peak Pluton and extrusion of the Coquihalla Group (Figure 2-1).

Jim Kelly Creek Camp (Table 3-9)

Aside from minor differences between mineral assemblages, prospects at Jim Kelly Creek are similar to those of the Summit Camp on Treasure Mountain.

Deposits in fracture zones consist of veins and quartz stringers up to one foot wide in zones up to 20 feet wide. Veins contain pyrite, galena, sphalerite, chalcopyrite, and minor amounts of tetrahedrite and chalcocite; quartz gangue is reported in every occurrence. The deposits are in schistose metavolcanic rocks of the Nicola Group which were affected by Late Cretaceous movement along the Pasayten Fault.

Similarities in form and mineralogy between Jim Kelly Creek and Summit

TABLE 3-9. CHARACTERISTICS OF DEPOSITS IN THE JIM KELLY CREEK CAMP

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Width	Attitude	Gangue	Mineralization
HSW-48 Gold Mtn.	vein	Nicola Group	metavolcanic schist	vein	2"-12"	N90E, S	qz	ga,py,cp,ap,tt
				faults offsetting vein		N-S	gouge	minor
HSW-49 Superior	vein	Nicola Group	schist	vein in fracture zone	4'-6'		qz, rock frags	ga,py,cp,tt
HSW-50 John Bull	vein	Nicola Group	metavolcanic and minor sedimentary schist	vein	6"-10"	N7E,45NW	qz	py,cp
HSW-51 Marsellaise	vein	Nicola Group	schist	fracture zone with stringers	3'		qz	py
HSW-52 Spokane	vein	Nicola Group	schist	fault zone	20'	N68W,35SW	qz	py,cp
				cross-fractures				low grade

Camp suggest similar modes and time of formation. As the Coquihalla Group is only four kilometers north of Jim Kelly Creek, it is suggested that volcanism provided heat and/or solutions and/or metals which migrated into fracture zones and deposited sulfide-rich veins.

Ladner Gold Belt (Table 3-10)

Unlike most vein deposits in the study area whose localization is generally unpredictable, veins in the Ladner gold belt occur consistently along the serpentine belt which marks the Hozameen Fault (Figure 2-1). East of the serpentine belt, slaty argillite of the Ladner Group is the most common host for gold veins, but serpentine and greenstones of the Hozameen Group, which lies west of the serpentine belt, are also mineralized. All three rock types and quartz veins are intimately associated along the belt.

Mineralization in quartz veins consists of native gold, auriferous arsenopyrite, pyrite, uncommon pyrrhotite, and rare chalcopyrite. Gangue minerals other than quartz and rare calcite are not reported (with the exception of HSW-35). Wall rock fragments commonly make up a good portion of the vein as at the Emancipation property (HSW-34) where the content of massive, milky quartz decreases away from the vein through a wide (about two meter) zone of brecciated slate in a groundmass of quartz.

Quartz veins are not required to localize mineralization; a few properties (HNW-3,27; HSW-60) report schistose (shear) zones of serpentine with sulfides and thin plates of native gold along foliations. Auriferous zones of talc also occur.

The prevailing hypothesis on the origin of sulfides has been that serpentinization of peridotite along the belt resulted in formation of veins and auriferous zones by providing easy access to deep-seated magmatic solutions (Cairnes, 1929). In recent years, geologists working in the area

TABLE 3-10. CHARACTERISTICS OF DEPOSITS IN THE LADNER GOLD BELT

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Attitude	Gangue	Mineralization
HNW-3* Aurum	vein	Ladner Group Hozameen Group	argillites greenstone serpentine	veins; sili- fied zones talcose shears		qz	Au,py,po,sp (cp)
HNW-4 Roddick	vein	Ladner Group	slate	vein	N50W,25SW	qz	
HNW-5 Emigrant	vein	Ladner Group	slate	veins		qz rock frags	
HNW-6 Snowstorm	vein	Ladner Group Hozameen Group	slate andesitic greenstone	veins wall rock	N55W,80NE	qz	po,sp,Au (py)
HNW-7 Idaho	vein	Ladner Group	slate	veins wall rock	N80W,45NE	qz rock frags	py,sp,Au
HNW-8 Montana	vein	Hozameen Group	andesitic greenstone	veins		qz	Au
HNW-9 Rush-of-the Bull Fr.	vein	Ladner Group	slate	veins wall rock		qz	sp,Au
HNW-10 Gem	vein		silicified,acid sill	vein wall rock		qz rock frags	py,sp
HNW-11* Pipestem	vein	Ladner Group	slate	stockwork vein and wall rock	N80W, +	qz,cb rock frags	py,sp,Au
HNW-13 Home X	vein	Ladner Group	slate	stringers	E-W	qz	py,sp
HNW-14 Star	vein	Ladner Group	slate	shear/vein	NW,50SW	qz	
HNW-25 Gem	vein	Ladner Group	slate	veins	N70W, +		py,sp
HNW-27 Brett	shear		serpentine	shear			Au
HNW-35 Gold Cord	vein			veins			Au
HNW-36 Gold Coin	disseminated	Ladner Group	slate at contact with serpentine	stringers		qz	
HNW-37 Majestic	vein	Ladner Group	porphyritic dike in slate	veinlets		qz	Au,py
HNW-46 Hillsbar	vein	Hozameen Group (?)	slate	veins		qz	Au
HSW-34* Emancipation	vein	Ladner Group Hozameen Group	slate greenstone feldspathic dikes	veins	N16W,50SW	qz,ca rock frags	py,sp,Au (cp,po)
HSW-35 Morning	vein	Ladner Group	slate greenstone	vein		qz,ca (gy)	sp,py (ga)
HSW-44 St. Patrick	vein		near quartz diorite/ serpentine contact	vein		qz	
HSW-60 Pacific Mines	shear		diorite dike/serpentine contact ("white rock")	shears			Au
HSW-95 Montana	shear	Hozameen Group	greenstone	shears			Au,Ag,Zn values
HSW-116 Camp	vein	Ladner Group	slate	veins		qz	po,py

have come to believe that major mineralized veins and shear zones are remobilizations of low grade (about 0.10 ounces/ton gold), disseminated, possibly syngenetic mineralization in the Ladner Group (cf. Kayira, 1975). According to Montgomery, et al., 1977, pyrite, arsenopyrite, pyrrhotite, minor amounts of chalcopyrite and native gold occur in albitized quartz-chlorite-carbonate schist which represents a coarse greywacke member of the dominantly argillaceous Ladner Group. Small quartz-carbonate-feldspar veinlets associated with mineralization cross-cut all formations including the Ladner and Hozameen Groups, and contained serpentine bodies (Sinclair, personal communication, 1977). Mode of origin is not clear, but if a syngenetic model is accepted, the age of mineralization before remobilization into quartz veins would be Lower to Middle Jurassic. Remobilization into veins and shears would have occurred during emplacement of the serpentine during major movement along the Hozameen Fault in early Late Cretaceous, prior to 84 Ma.

23-Mile Camp (Table 3-11)

The 23-Mile Camp is characterized best by its diversity in types of mineral occurrences. Most deposits occur in Hozameen Group limestone, greenstone or dikes, but one is in Ladner Group slate and two are in small plutons which intrude the Ladner Group. Hozameen-hosted deposits include four skarns (HSW-3,12,41,117), one disseminated occurrence (HSW-42; in andesite), and two vein deposits (HSW-25,117). Ladner-hosted deposits include one copper-nickel occurrence (HSW-1), two vein deposits in quartz diorite (HSW-2,27), and a breccia pipe made up of fragments of disrupted argillite (HSW-1). This breccia pipe, Canam, is the fourth largest deposit in the study area, with reserves estimated at eight million tons grading 0.61 percent copper; it is the only deposit to report uranium in the study area.

TABLE 3-11. CHARACTERISTICS OF DEPOSITS IN THE 23-MILE CAMP

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Width	Attitude	Gangue	Mineralization
HSW-1* Canam	porphyry	Ladner Group	siliceous and argillaceous sedimentary rocks	periphery of breccia pipe			qz,ca,cl,to,ep,am,fd	py,cp,po (mg,mo,sl, ga,ap,sh,ur)
			hornblendite	lenses			qz,ca,ak	cp,po (sl)
HSW-2* Invermay	vein	Invermay Stock	altered quartz diorite	lenses in shear zone	1"-6"	variable	qz	ga,sl,ap,cp (py,jm)
			"banded rock"	dark bands			to (qz)	py,cp
HSW-3 Mammoth	skarn	Hozameen Group	lime/silicate belt in cherty sedimentary rocks and massive greenstones		50'		qz,ca,sd	po,sh,sl,pr,mo,st
HSW-12 D + J	skarn	Hozameen Group	chert, volcanic rocks and some limestone	fractures	20'	NW, + S	gt,qz,ep,hb,wo,ac	po,cp (sl,ap,ga,Cu)
HSW-25* Silver Daisy	vein	Hozameen Group	"cherty member"	lenses in shear zone	2"-8"	N65E-N20E	qz, gouge	po,sl,cp,ga,ap (tt)
HSW-27 July	vein	Invermay Stock	quartz diorite	lenses in shear zone	3'-4'	NE, + E	qz, gouge, rock frags	sl,ap,cp
HSW-41 Defiance	skarn		limestone and diabase dike	contact	12'-30'			po
HSW-42* B.B., Rainbow	disseminated	Hozameen Group	andesite and granular quartzite	joints; fractures		NE,90		po,cp,ap,py,ga (jm)
HSW-117 Star #1	vein		hornblende andesite	vein	6"-1'	N80E,80SE	qz	ap,ga
			limestone/greenstone	contact				ga (cp,po,sl)
HSW-118 Forks	magmatic		peridotite (?)					po
HSW-125 Mammoth	magmatic		pyroxenite	dikes	less than 10'			po,sl,cp

In contrast to the diversity of deposit types, a major similarity in deposits of this camp is mineralogy. Chalcopyrite is present in ten of fourteen cases, sphalerite and pyrrhotite in nine, galena and arsenopyrite in seven.

Mineralization in the Ladner Group probably can be attributed to intrusion of the Invermay Stock. A smaller pluton two miles northwest of the Invermay Stock has been dated at 84 $\pm$ 6 Ma. Since these two bodies are lithologically similar, they are considered to be contemporaneous. Deposits in the Hozameen Group cannot be dated as easily. An important point is that the Ladner-Hozameen contact is the Hozameen Fault, which is cross-cut by the 84 Ma pluton discussed above. If most deposits in this camp are related to the stocks as products of the same mineralizing event (due to mineralogical similarities and proximity), a post-faulting age of 84 Ma or younger is required. The 84 Ma age is adopted in this study.

Ultramafic rocks and related mineralization most likely are related to pre-84 Ma thrusting along the Hozameen Fault, and therefore constitute an early episode of mineralization.

<u>10-Mile Creek Camp</u>[8] (Table 3-12)

Sulfides in the 10-Mile Creek Camp occur in lenses, veins, fractures and as disseminations. Pyrite, pyrrhotite, chalcopyrite, sphalerite and arsenopyrite occur commonly with quartz, but calcite has been reported; magnetite, stibnite and galena are rare. One showing (HSW-82) is in quartz diorite, two minor ones (HSW-28,55) are in porphyritic diorite dikes, and the other seven occurrences are contained in Hozameen Group greenstones or limestone (?).[9]

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[8] The large number of occurrences recognized in this camp resulted from intense exploration during a promotional swindle in 1910; by 1911 interest in the area had declined considerably. No production occurred in this camp.

[9] Rocks and alteration associated with mineralization have not been studied in detail; descriptions like "soft, white, decomposed rock" are common.

TABLE 3-12. CHARACTERISTICS OF DEPOSITS IN THE 10-MILE CREEK CAMP

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Width	Attitude	Gangue	Mineralization
HSW-9 Billican Group	disseminated	Hozameen Group	sedimentary rocks and andesite	veins, stringers and lenses in fractures			qz	py,sl,po,cp,sb,ap,ga,jm
HSW-14 Gold Coin	massive	Hozameen Group		lenses			qz,ca	py,sl
	disseminated			fractures near quartz diorite				sl
HSW-28 Sunrise	disseminated	Hozameen Group	limestone (?)	lenses, stringers and disseminations			qz	py,sl,ga
			diorite	dike				py,sl
HSW-55 Steamboat Mtn.	disseminated	Hozameen Group	quartzite, argillite	lens			qz	py,cp,po,ap
			porphyritic diorite	dike				py,cp
HSW-58 Utah	disseminated	Hozameen Group	ferruginous limestone	stringers and disseminations			qz,ca	py,cp
HSW-82 North Star	disseminated		quartz diorite	veins	6"-1'		qz	ap,ga,sl,po
		Hozameen Group	greenstone close to intrusive	disseminations				sp
HSW-109 Skagit Giant	massive	Hozameen Group	andesitic greenstone	injected (?) lens			none	po,py,cp
			greenstone	lens			gt,ep	py,mg
HSW-121 occurrence	vein	Hozameen Group	greenstone	fissured zone	4'-6'		qz	py,cp,po,sb
HSW-122 occurrence	vein	Hozameen Group	limestone (??)	veins	2"-10"		(qz)	sl,ap
				vein	1'-2.5'		(qz)	py,po,ap
HSW-123 occurrence	massive	Hozameen Group	andesite	lens			qz (at,sn)	mg

Skarnification is commonly reported, but only one deposit (HSW-109) reports a skarn assemblage. Positive identification of limestone is rare, therefore, it is unlikely that this mode of origin can satisfactorily describe the entire district.

Dikes and other intrusive rocks in the area have been looked upon as mineralizing sources because they commonly contain disseminated sulfides. However, dikes may have picked up sulfides from pre-existing accumulations during intrusion. The undefined nature of massive and disseminated mineralization in this camp suggests that sulfide deposits, like their host rocks, have undergone deformation. The precise character of sulfide bodies prior to deformation is not known.

The association of copper-zinc mineralization in greenstones might lead to speculation that massive, disseminated and vein deposits are related to syngenetic volcanic accumulations, but much more data are necessary. Age of mineralization is either Paleozoic (if syngenetic) or mid-Cretaceous (if epigenetic or remobilized during deformation).

<u>Harrison Lake District</u> (Table 3-13)

The Harrison Lake Formation contains abundant disseminated copper-zinc mineralization. Chalcopyrite, sphalerite, pyrite and rare galena and pyrrhotite occur as veinlets associated with fractures in calc-alkaline, locally pyritic, pyroclastic volcanic rocks. Quartz gangue and/or silicification is common. One report describes calcite gangue, and another reports barite. Some reports do not describe gangue minerals.

Early descriptions of the Seneca volcanogenic deposit (HSW-13) are much like those of other deposits in the Harrison Lake Formation. Although work began on Seneca in 1898, it was not until 1971 that <u>Geology, Exploration and Mining in British Columbia</u> reported a stratiform lens of massive

TABLE 3-13. CHARACTERISTICS OF DEPOSITS IN THE HARRISON LAKE DISTRICT

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Attitude	Gangue	Mineralization
G-145 Rat	disseminated	Harrison Lake Formation	volcanic	gossan			(Cu and Zn traces)
G-154 Cleveland	disseminated	Harrison Lake Formation	brecciated, silicified rhyolite tuff	veinlets		qz	cp,sl,py,po,Bi,mg,cc
HSW-13* Seneca	volcanogenic	Harrison Lake Formation	rhyolite lapilli tuff and breccia			qz,ca,ba	py,cp,sl,cv,tt,ga,mr
HSW-15* Valley View	disseminated	Agassiz Prairie Formation	greywacke metavolcanic rocks	fractures gossan		(qz)	py,cp (1966 info) cp,bo,cc (1974 info)
HSW-96 Luv	disseminated	Harrison Lake Formation	andesite flows and agglomerate	fractures			cp,sl,py
HSW-103 IAM	disseminated	Harrison Lake Formation	rhyolite	stringers in breccia pipe		ba	sl,cp,ga
HSW-106 Fab	disseminated	Harrison Lake Formation	silicified, pyritized, fractured agglomerate	stringers		qz	py,cp,sl,cc
HSW-112 Ascot	disseminated	Harrison Lake Formation	andesite flows and breccia	fractures		qz	py,cp,sl
HSW-113 Sku	porphyry	Harrison Lake Formation		alteration halo around granite pluton			py
HSW-114 SF	vein	Harrison Lake Formation	pyritized, sericitized andesite flows			qz	cp,sl,py
HSW-115 Top	vein	Harrison Lake Formation	silicified, epidotized, pyritized pyroclastics	blebs and veinlets in shear		qz,ca	ga,cp,po
HSW-120 KU	disseminated	Harrison Lake Formation Echo Island Formation	felsic volcanic rocks sedimentary, tuffaceous				sl,cp (py,po)
HSW-126 J No.6	disseminated	Harrison Lake Formation	porphyritic andesite and flow breccia	shear which parallels 10' wide pyritized tuff band	N70W,65SW		cp

sulfides interpreted as syngenetic mineralization. On this basis, other vein or disseminated showings with structure and mineralogy similar to that of Seneca might be re-interpreted as small volcanogenic manifestations. In this interpretation, age of mineralization in the district would correspond to the mid-Jurassic age of the Harrison Lake Formation. Of course, concentration of sulfides by later hydrothermal fluids flowing through the sulfide-rich volcanic rocks also would be a possibility, but initial mineralization would be syngenetic, and there seems to be no evidence that implies a superimposed remobilizing event. Some vein stages of the volcanogenic system can continue beyond the period of host rock deposition; these would be slightly younger than host rocks.

<u>Fire Lake Camp</u> (Table 3-14)

The Fire Lake Group is dominantly sedimentary in origin, but includes greenstones which contain five of the six deposits reported in the formation. Deposits in greenstone are quartz veins with chalcopyrite and, commonly, native gold. Veins are not continuous but consist of lenses and gash veins in a wider (possibly sheared) zone. The sixth deposit is contained in a belt of brecciated sedimentary rocks which enclose lead-zinc mineralization in quartz and calcite gangue.

An origin by hydrothermal action along zones of weakness during intrusion of surrounding plutons is most likely. Age of mineralization is therefore Late Cretaceous.

<u>Pitt Lake</u> (Table 3-15)

Most deposits in the Pitt Lake area are quartz veins in intrusive rocks of the Coast Plutonic Complex; similar mineralization is scattered throughout the Coast Plutonic Belt. The veins at Pitt Lake carry pyrite, chalcopyrite, uncommon galena and pyrrhotite, and rare sphalerite and covellite.

TABLE 3-14. CHARACTERISTICS OF DEPOSITS IN THE FIRE LAKE CAMP

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Width	Attitude	Gangue	Mineralization
G-26* Money Spinner	vein	Fire Lake Group	porphyritic greenstone	vein in shear zone	3'-4'	N10W,60SW	qz	py,cp,Au,bo
G-27 Barkoola	vein	Fire Lake Group	greenstone	parallel veins and lenses in 25' wide zone	up to 2'		qz	cp,Au
G-28 Blue Lead	vein	Fire Lake Group (?)		4 parallel lenses	up to 18"	N85E,45NE	qz	cp,Au
G-29 King No.1	vein	Fire Lake Group	greenstone	gash veins	up to 36"		qz	cp
G-30 Richfield	vein	Fire Lake Group	greenstone	gash vein	0-14"	E-W,26N	qz	
G-36* Dandy	vein	Fire Lake Group	brecciated sedimentary rocks	vein				py (ga,sl)
				breccia belt	100'-200'		qz,ca cement	ga,sl (py)

TABLE 3-15. CHARACTERISTICS OF DEPOSITS IN THE PITT LAKE AREA

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Width	Attitude	Gangue	Mineralization
G-1 Jubilee	vein			stringer(s)			qz	py,cp
G-7 St. Paul	vein	Coast Plutonic Complex	diorite	vein	1'-1.5'	N55W,90	qz	py,cp
G-20 Standard	vein	Coast Plutonic Complex	quartz diorite	fractures	2"-1' 2"-4"	N25E,80NW N25E,80NW	qz	py,ga,cp
G-34* Viking	vein	Coast Plutonic Complex	granodiorite	shear zone		N90E,80S	qz, ko (ca) rock frags	py,po,cp (cv,sl)
G-82 St. John	vein			vein	2"-4"	NW,90	qz	py,cp

TABLE 3-16. CHARACTERISTICS OF DEPOSITS ON THE SECHELT PENINSULA

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Width	Attitude	Gangue	Mineralization
G-23* Cambrian Chieftan	skarn	Gambier Group	limestone	fractures in skarn			gt, ep	cp,py,mg,sl (ml,cc,cv)
G-24* King Midas	skarn	Coast Plutonic Complex Gambier Group	granite/granodiorite calcareous remnant	irregular, altered, silicified contact zone			ep,gt,ca,mg	cp,py,Cu,sc
G-84 Sundown	porphyry							Cu,Mo
G-93 War	porphyry	Gambier Group Coast Plutonic Complex	volcanic rocks, skarn, and hornfels granite	stockworks shears			qz	cp (mo) cp,mo
G-94 Day	skarn	Gambier Group	chert, limestone (near intrusions)	vein-like bodies along contact				cp,py,mg,sl
G-138 M.C.	skarn	Gambier Group	limestone, dolostone	shear				mg,py,cp

Veins are relatively narrow (two inches to one and one half feet) and are steep to vertical; no preferred orientation is apparent.

The origin of veins in plutonic rocks is attributed to late stage hydrothermal activity of host plutons in Late Cretaceous time.

Sechelt Peninsula (Table 3-16)

Although skarns are uncommon in the Coast Plutonic Belt, four skarn deposits occur on the Sechelt Peninsula. Deposits were formed in limestone of the Gambier (?) Group during intrusion of surrounding plutons of the Coast Plutonic Complex. Characteristic skarn assemblages consist of garnet, epidote, magnetite, pyrite and chalcopyrite; some sphalerite, native copper and specularite have also been reported. Age of mineralization corresponds to plutonism in mid-Cretaceous time.

In addition to skarn mineralization, two porphyry occurrences appear in this area. They are typical of most porphyry deposits of the Coast Plutonic Belt, consisting of disseminated copper and molybdenum sulfides in plutonic (and rarely pendant) rocks. The age of porphyry mineralization probably is equivalent to that of the plutonic rocks and skarns.

ISOLATED PAST PRODUCERS AND IMPORTANT PROSPECTS

Table 3-17 presents information on deposits with production records that were not discussed previously because of their isolated locations outside designated camps and districts. The Zel and Gem deposits are included and discussed individually because they are the most accurately dated deposits in this section.

Zel

A small muscovite granite pluton intrudes biotite granodiorite of the Coast Plutonic Complex 20 kilometers east of Squamish on the Zel property

TABLE 3-17. CHARACTERISTICS OF ISOLATED PRODUCERS AND IMPORTANT OCCURRENCES.

Mac No. Name	Type of Deposit	Host Rock Formation	Host Rock Type	Mineralized Structure	Width	Attitude	Gangue	Mineralization
G-5 Zel	porphyry	83.4 Ma pluton	muscovite granite (some pegmatite)	veins and disseminations	up to 2.5'		qz	bo,cp,cv,mo
G-14 Lorraine	shear	Bowen Island Group		two shears		N35W,80N		py,cp,po,ml,az
G-25 Ashloo	vein		basic dike (?) intrudes granodiorite	bands, lenses and stringers in shear			qz	py,cp,po
HSW-8 Empress	skarn	Chilliwack Group	limestone				gt,ca,fd,ep	cp,bo,mg,py,mo,wo, az,ml
HSW-11 Eureka-Victoria	vein	Chuckanut Formation	conglomerate	fracture zone			sd,qz	py,tt,mr,ml,az
HSW-33 Anna	skarn	Chilliwack Group	limestone				ep,gt	cp,ml,az,cc
HSW-36 Aufeus	vein	Spuzzum pluton	quartz diorite	shear with veins	1-12" 2"-2'	N85E,50S N77E,40S N77E,23S N82E,43S	qz,ca	ap,py,cp
HNW-1 Gem	porphyry	34.2 Ma intrusion	quartz monzonite porphyry	disseminations and veins in and around breccia pipe			qz	mo (py,po,cp,sh,sl,Bi)
HNW-2 Providence	vein	Harrison Lake Formation		vein			qz	py,Au

(G-5). Chalcopyrite, bornite, covellite and molybdenite occur as disseminations, in quartz veins and in pegmatites related to the granite plug. A K/Ar date of 83.4 ± 4.2 Ma was obtained from granite, and is used to approximate the age of mineralization (G. J. Woodsworth, personal communication, 1978).

Gem

Porphyry mineralization of the Gem deposit (HNW-1) is related genetically to a quartz monzonite porphyry breccia pipe. The pipe is associated with a small granitic plug which intrudes Settler Schist and Custer Gneiss. Molybdenite occurs as disseminations in host rocks, in quartz veins and in massive molybdenite veins. Veins are randomly oriented in all rock types, but are highly concentrated around the contact between the pipe and the granite into which the pipe intrudes. Pyrite, pyrrhotite, chalcopyrite, scheelite, sphalerite and bismuthinite occur locally in quartz veins, and gold values up to 0.02 ounces/ton were reported in 1938.

Age of mineralization corresponds to intrusion of the quartz monzonite porphyry breccia pipe. A K/Ar date on biotite from the quartz monzonite indicates intrusion occurred at least 34.2 ± 1.2 Ma (R. L. Armstrong, personal communication, 1978).

Other Deposits

The remaining deposits are skarns, veins and one shear. The formation of skarn deposits can be attributed with relative certainty to intrusion of plutons, but the age of veins and shears can only be estimated. Veins in plutonic and non-plutonic rocks are probably results of intrusion of host or nearby plutons, but mineralization could have occurred at any time after formation of the host rock. Estimations of deposit ages are as follows:

G-14	Lorraine	Cretaceous ?

G-25	Ashloo	Upper Cretaceous ?
HSW-8	Empress	late Oligocene or Miocene
HSW-11	Eureka-Victoria	Miocene (21 Ma)
HSW-33	Anna	late Oligocene or Miocene
HSW-36	Aufeus	Upper Cretaceous (83 Ma)
HNW-2	Providence	Upper Cretaceous ?

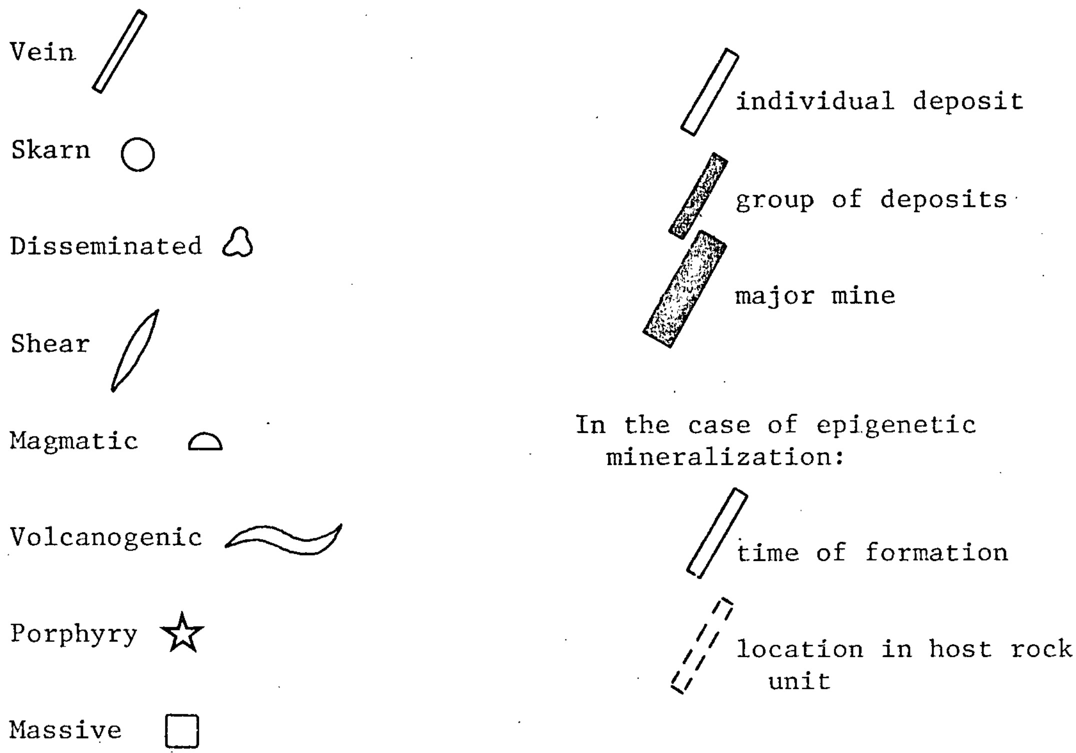
Absolute ages assigned to HSW-11 and 36 are based on K/Ar dates on plutonic rocks less than one kilometer from the deposits.

SUMMARY

The metallogenic history of the study area as discussed in this chapter is presented in Figure 3-4 and Table 3-18. Figure 3-4 is a duplicate of the time-space plot of Figure 2-2 onto which mineralization of districts, camps and individual producers has been superimposed. An explanation of the symbols used in this figure is contained in Figure 3-4a. In the case of the Britannia and Harrison Lake Districts, volcanogenic mineralization represents all occurrences except porphyries. Where more than one possibility exists as to the origin of a deposit, all possibilities are indicated and accompanied by question marks. If a dashed-line symbol is not present for epigenetic occurrences, mineralization is assumed to be about the same age as its host (e.g., veins in the Coast Plutonic Complex).

Table 3-18 describes the distribution of metal deposits through time with respect to actual and/or potential causative events.

Figure 3-4a. Explanation of Symbols on Figure 3-4.



1. Britannia District
2. Northair District
3. Giant Mascot District
4. Eagle Belt
5. Summit Camp
6. Jim Kelly Creek Camp
7. Ladner Gold Belt
8. 23-Mile Camp
9. 10-Mile Creek Camp
10. Harrison Lake District
11. Fire Lake
12. Pitt Lake
13. Sechelt Peninsula
14. Zel
15. Gem
16. Lorraine
17. Ashloo
18. Empress
19. Eureka-Victoria
20. Anna
21. Aufeus
22. Providence

TABLE 3-18. SUMMARY OF METALLOGENIC HISTORY

TIME SPAN	EVENTS	DISTRICTS, CAMPS AND DEPOSITS INVOLVED
I. Pre-Devonian		
II. Upper Paleozoic/ Lower and Middle Triassic	deposition of volcanogenic sulfides in the Hozameen Group ?	10-Mile Creek Camp ?
III. Permian/Triassic		
IV. Upper Triassic		
V. Lower and Middle Jurassic	deposition of syngenetic gold in the Ladner Group ?	Ladner Gold ?
	deposition of volcanogenic sulfides in the Harrison Lake Formation	Harrison Lake District
VI. Upper Jurassic		
VII. Lower Cretaceous	porphyry and vein mineralization during late stages of formation of the Eagle Complex	Eagle Belt
	magmatic sulfide formation in Giant Mascot Ultramafite	Giant Mascot District
	deposition of volcanogenic sulfides in the Gambier Group	Britannia District
	deposition of volcanogenic sulfides in the northern Gambier (?) Group ?	Northair District ?
VIII. mid-Cretaceous (limits undefined)	vein formation near the Hozameen Fault and introduction of disseminated gold (?) into the Ladner Group during movement of the Hozameen Fault	Ladner Gold Belt
	formation of epigenetic disseminated, massive and vein deposits in the Hozameen Group during deformation ?	10-Mile Creek Camp ?
IX. Upper Cretaceous	skarn, vein and porphyry mineralization in the Coast Plutonic Complex and Spuzzum pluton during late stages of plutonism	Sechelt Peninsula, Lorraine, Northair District, Pitt Lake, Ashloo, Fire Lake, Providence, Aufeus, Zel
	skarn, vein, porphyry and disseminated mineralization in the Hozameen Group related to intrusion of small pluton(s) ?	23-Mile Camp ?
X. Tertiary	porphyry mineralization associated with minor late plutonism in the Spuzzum Plutonic Belt	Gem
	skarn and vein formation during intrusion in the Cascade Belt	Anna, Empress, Eureka-Victoria
	vein mineralization in fracture zones in the Ladner Trough and Eagle Plutonic Belt possibly related to extrusion of the Coquihalla Group ?	Summit Camp, Jim Kelly Creek Camp

4. COMPUTER STUDY

INTRODUCTION

This chapter deals with the statistical aspects of mineral occurrences. The main concern is to catalogue and analyse available information on sites at which metals have been concentrated and to draw conclusions relative to the genesis of these concentrations.

In theory, the value of a computerized mineral deposits file such as MINDEP is that it enables fast retrieval and reorganization of large amounts of data which would be tedious to deal with manually (cf. Orr and Sinclair, 1971). If the data bank is set up properly and programs are available for selective information retrieval and organization, the time spent by the regional geologist or metallogenesist acquiring data is minimal. After geological and related features of each deposit are entered into the system, deposits may be grouped easily on the basis of a wide variety of parameters. Evaluation of such data might lead to rapid appraisal of characteristics and controls of mineralization.

The variables examined below are commodities (specifically metals), deposit type, tectonic setting, host rock formation and host rock type. Data are presented on histograms; numerical values are tabulated in contingency tables in Appendix A. Spatial distribution and zonation of metals and deposit types are presented on maps produced directly from the computer on a Calcomp plotter.

Commodities are reported in the literature either as assays or by the presence of sulfides of the metal concerned.[1] In some cases, mining claims were staked on the assumption that certain metals were present, although

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[1] An exception is iron, which occurs in nearly all deposits as pyrite (and rarely as siderite and pyrrhotite), but is usually not reported unless there are concentrations of magnetite.

subsequent work has not verified these assumptions. Many such instances were noted in the literature, and the unrecognized commodities were deleted from the data file; some errors in this regard might still be present.

Inaccurate and/or incomplete sources of information prevented systematic evaluation of the relative importance of metals between and within deposits. Wherever possible, metals are listed in order of abundance or economic importance, but statistical counts of metal occurrences consider each metal in a deposit with equal emphasis. It is believed that the presence of a metal is the primary concern, regardless of amount or concentration, but where information is available, metals with only trace assay values were deleted. On the other hand, metals have been included by the writer where a metal sulfide has been reported to occur (commonly in unknown amounts), but the contained metal was not included in the description of the occurrence by previous reporters. Deposits with production records (referred to as "producers") are distinguished on histograms in order to compare viable economic occurrences with those that did not produce. Five deposits (Table 4-1) whose sizes greatly exceed the average deposit size in the study area are distinguished also.

Further description of deposit types on the basis of metal content is presented in Figure 4-1. These histograms identify metal associations in each type of deposit, and can be referred to when clarification of metal and deposit type relationships is required in the subsequent discussion.

Host rock formation refers to the unit in which mineralization occurs, whether it is a formation, group, or named pluton; it is not specified for some deposits in small units of unknown correlation, dikes, or small plutons of unknown age. However, host rock type applies to every deposit for which a description is available.

Zoning maps require a method of recognizing deposit size, but since the

TABLE 4-1. GRADE AND TONNAGE OF MAJOR DEPOSITS

	Cu	Pb	Zn	Au	Ag	Ni	Production	Total Resources
Britannia[1,2] G-3	1.1%		.65%	.02oz/T	.20oz/T		52,783,964 T	
Giant Mascot[1,3] HSW-4	.33%					.77%	6,081,133 T	7,577,000 T
Northair[4,5] J-130		2.7%	4.0%	.40oz/T	4.60oz/T			330,637 T
Canam[6] HSW-1	.61%							8,000,000 T
Aurum[7] HNW-3				.098oz/T				3,650,000 T

[1]Data calculated from production records.

[2]British Columbia Department of Mines and Bureau of Economics and Statistics, Victoria, British Columbia

[3]British Columbia Department of Mines and Bureau of Economics and Statistics, Victoria, British Columbia, and Christopher and Robinson, 1974

[4]Data calculated from reserves estimate.

[5]Northair Mines Ltd., Annual Report, 1977

[6]Pilcher and McDougall, 1976

[7]Montgomery, et al., 1977

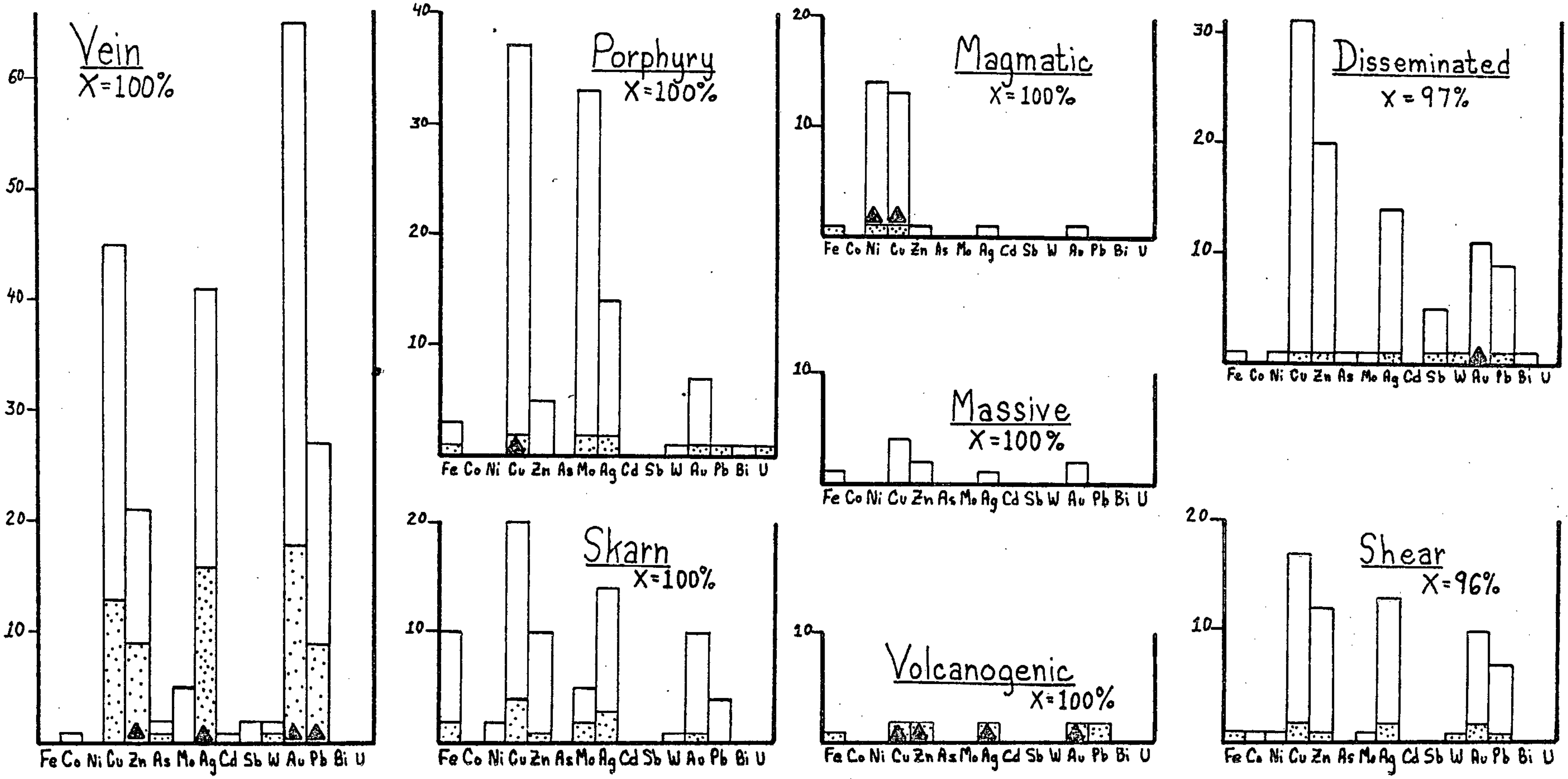

Figure 4-1. Number of occurrences of each deposit type with respect to characteristic metals. "X" is the percent of total occurrences of each deposit type in the study area for which metal content is known. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent all others (see Table 4-2).

dimensions of very few deposits are known, a rating system of the magnitude of deposits according to the status of exploration or production has been defined as a substitute (see Table 4-2). Magnitude I, the smallest, includes both showings and prospects because for many the distinction between them is based on whether or not geochemical or geophysical surveys were made. These remote sensing techniques are employed commonly in recent exploration programs, whereas older programs relied principally on surficial mapping. Magnitude II is assigned to developed prospects, because although they have not produced, they have attracted more attention than showings and prospects. Magnitude III is assigned to deposits which produced several thousand tons or less. The five major deposits of Table 4-1 are of magnitude IV.

Each commodity is examined first with respect to its distribution among deposit types to determine if metals occur preferentially in any particular type. Subsequent studies examine distributions relative to tectonic setting, host rock formation and host rock type. A final section examines the areal distribution of metals and deposit types for regional zoning patterns which might relate to deposit genesis.

METAL AND DEPOSIT TYPE ABUNDANCES

Copper is reported in 73 percent of all deposits (Figure 4-2), but the percentage of deposits which produced copper (10 percent) is the same as gold and silver, which are found in 45 percent of all deposits. Zinc has been reported in more cases than its common associate, lead, but the percentage of producers for each (5.6 percent) are equal because deposits which produce one commonly produce the other. Molybdenum is more common than the remaining reported metals. Very few deposits reporting molybdenum have proven economic, but the number of molybdenum producers is approximately that of iron, arsenic and tungsten, which are much less common than molyb-

TABLE 4-2. DEPOSIT STATUS BASED ON HISTORY OF EXPLORATION, DEVELOPMENT OR PRODUCTION

Status	History	Magnitude	Number of Deposits
Showing	no development or significant exploration, or no description of mineralization available	I	152
Prospect	geochemical or geophysical survey, and/or detailed mapping, or developed by open cuts or short adits	I	55
Developed Prospect	considerable exploration and development, well-established camp facilities; rarely some ore has been mill tested	II	20
Past Producers	production record of several thousand tons or less	III	30
	production record over several hundred thousand tons	IV	4
Producers	currently producing deposits	IV	1

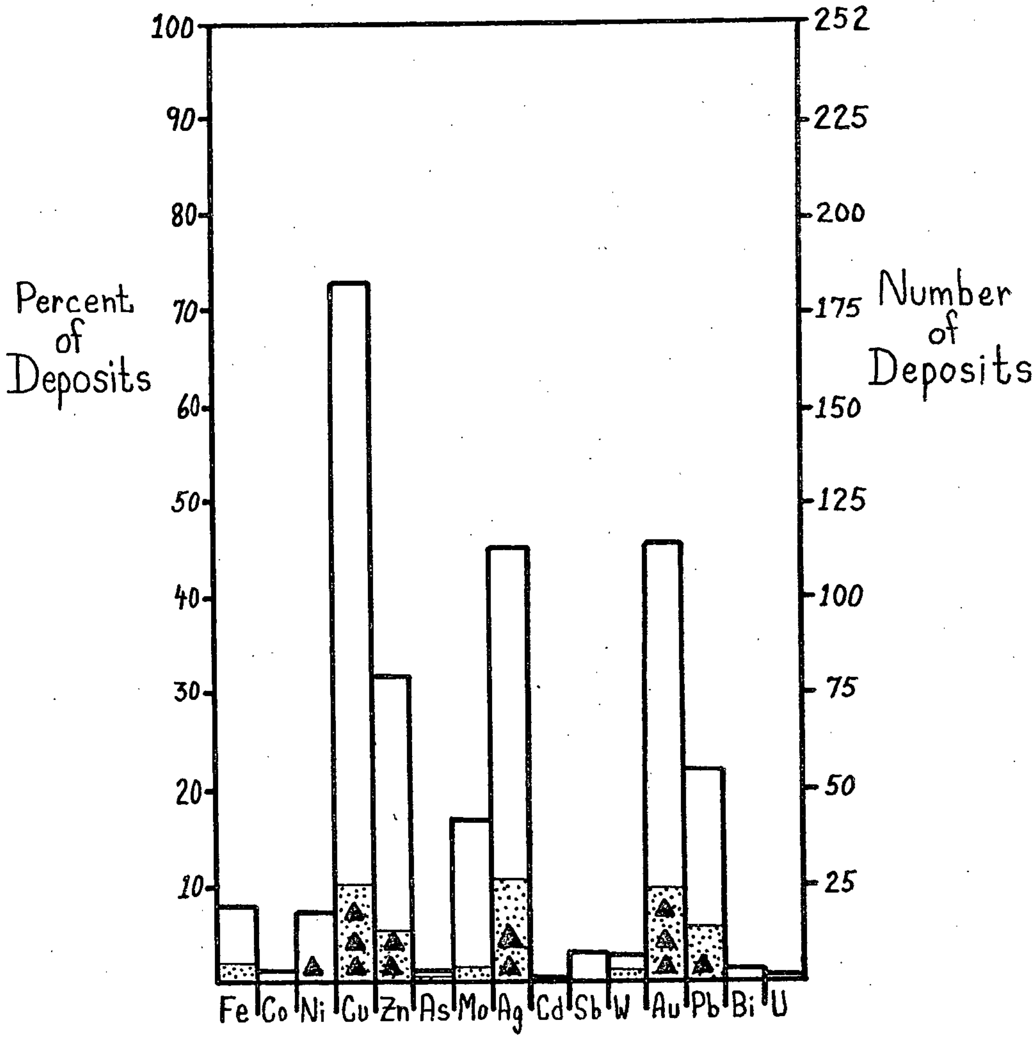

Figure 4-2. Total number of occurrences of each metal (metal content is known for 97.9% of all deposits in the study area). Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

denum. The distribution of major deposits (Figure 4-2) roughly reflects general abundances and percentages of producers. Similarly, the distribution of producers reflects the abundance of metal occurrences. Nickel is an exception; the only deposit to produce was a major one.

Figure 4-3 portrays the distribution of deposits among the eight types found in the area. Veins are by far the most common deposit type, and the most common type to go into production, as nineteen vein deposits are producers, whereas no other type includes more than three producers. Porphyries and disseminated deposits are about half as abundant as veins; skarns and shears each account for ten percent of all deposits. It is interesting to note that the two recognized volcanogenic deposits are producers, although the correlation is probably not significant, but more a reflection of the lack of recognition of other deposits as volcanogenic; many disseminated, vein and shear deposits might, in fact, be volcanogenic in origin. Major deposits do not demonstrate close ties with any particular type of deposit, but are evenly distributed among most types. Magmatic and volcanogenic types are relatively uncommon, but include major deposits.

POSSIBLE ORE CONTROLS

Deposit Type

Figure 4-4a,b illustrates the distribution of the most common metals among deposit types. Metals reported in less than five percent of deposits are not shown because they lack a substantial data base and limited available information is not definitive. Each metal distribution pattern can be compared to that of Figure 4-3; different distribution patterns for metals relative to each deposit type suggest that the occurrence of the metal is controlled by deposit type. Generalizations made from these distributions regarding metal sources are speculative, but are mentioned where appropriate.

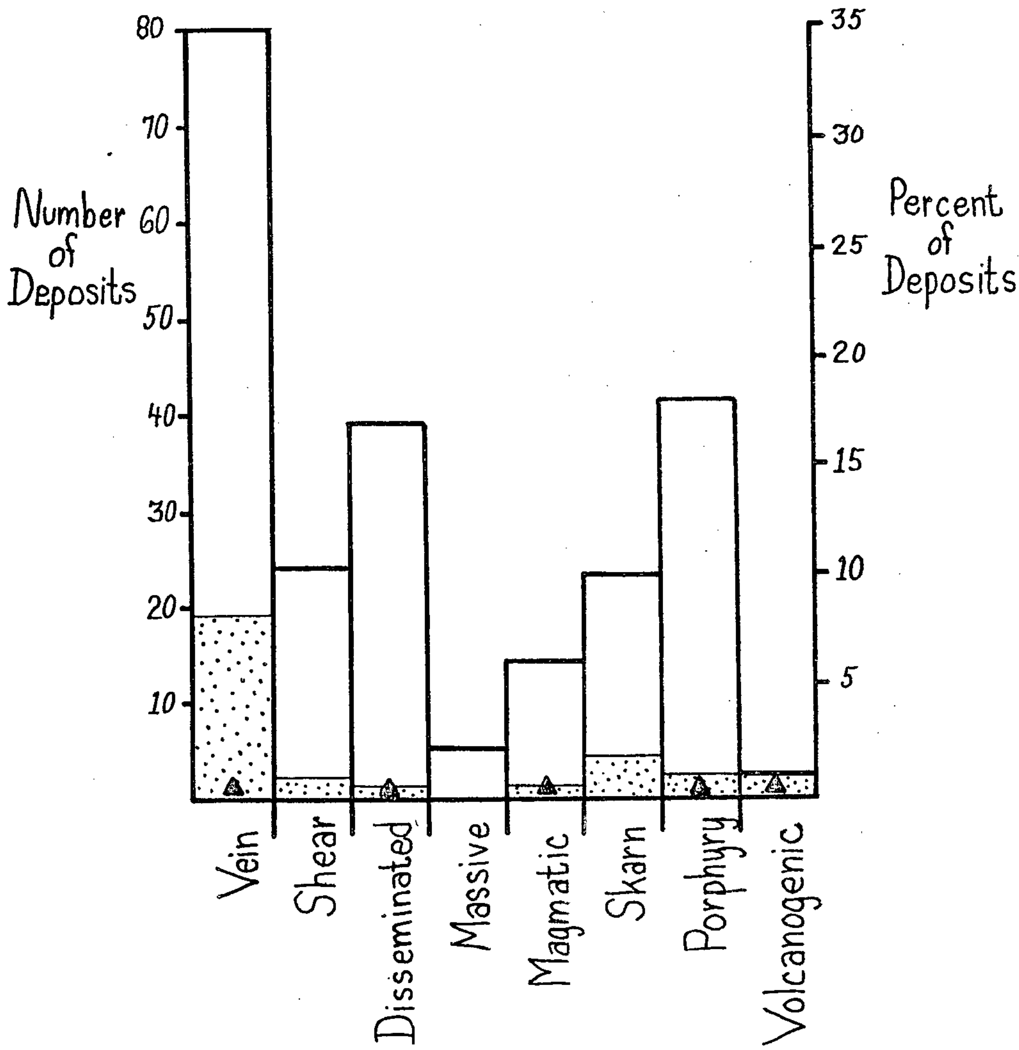

Figure 4-3. Total number of occurrences of each deposit type (deposit type is known for 88.4% of all deposits in the study area). Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

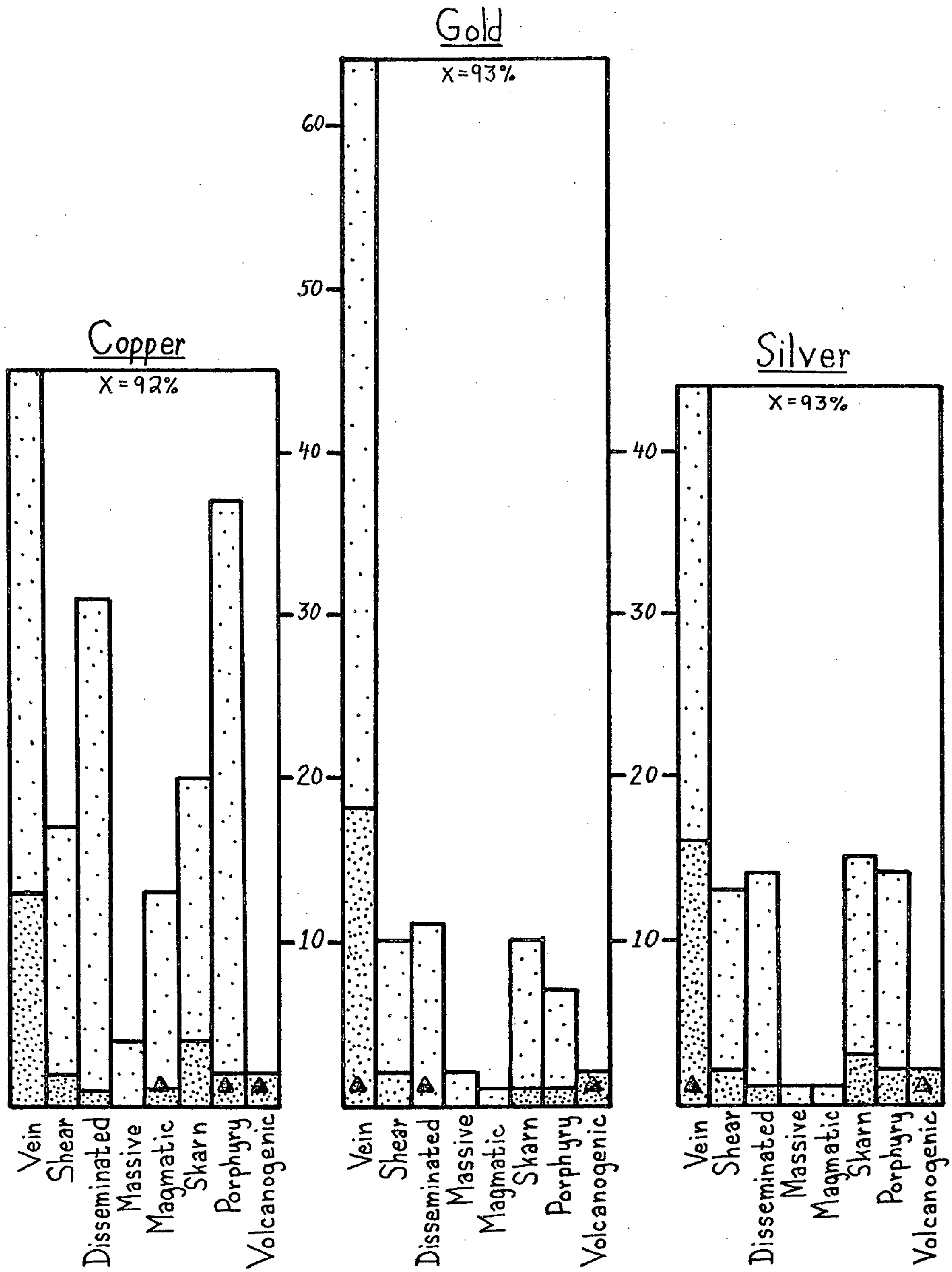

Figure 4-4a. Number of occurrences of copper, gold and silver with respect to deposit type. "X" is the percent of total deposits of each metal for which deposit type is known. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

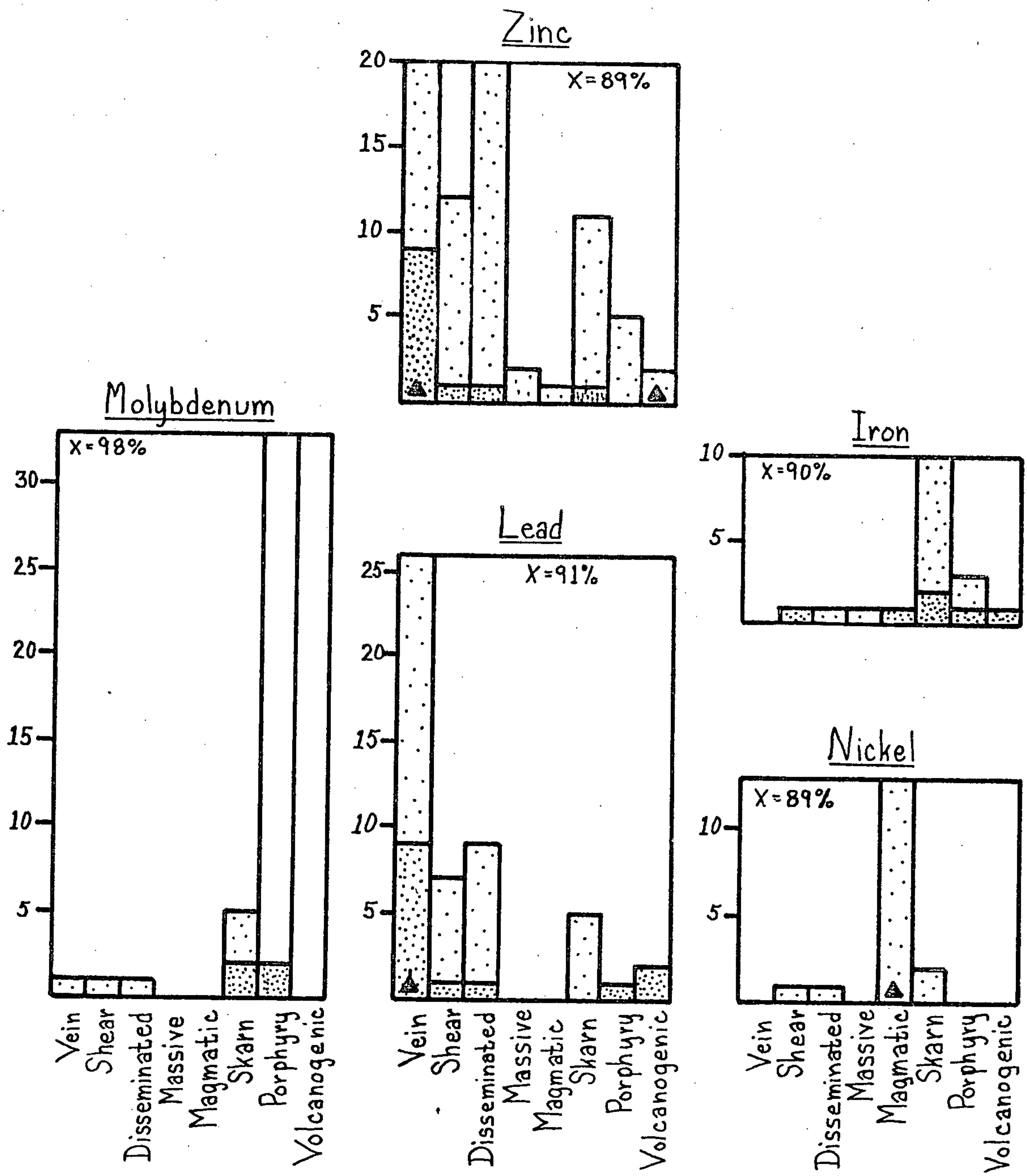

Figure 4-4b. Number of occurrences of molybdenum, zinc, lead, iron and nickel with respect to deposit type. "X" is the percent of total deposits of each metal for which deposit type is known. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

The distribution of copper (Figure 4-4a) is much the same as that of deposit types (Figure 4-3), reflecting the diverse and widespread occurrence of the metal.

Gold and silver occur dominantly in veins, but whereas gold is singularly dominant in veins, silver is reported also in other types of deposits. The ratio of silver occurrences to gold occurrences in disseminated, shear, skarn and porphyry deposits is 1.27, 1.30, 1.50 and 2.00, respectively.

Molybdenum (Figure 4-4b) is prominent in porphyry deposits, suggesting that intrusive activity is responsible for the concentration of molybdenum. Further support for this hypothesis comes from the fact that skarns are the only other type of deposit to report molybdenum with any significant frequency (five of 23 skarns in the area report molybdenum).

The distribution of lead shows a dominance in veins, and a conspicuous absence in porphyry and magmatic deposits. Zinc is almost as widespread as copper, generally occurring in veins or disseminated deposits. Shears and skarns also report considerable zinc.

Iron oxides are not reported commonly. Not enough data are present to generalize beyond the fact that they are reported most often in skarns.

Nickel is reported as uncommonly as is iron, and is restricted to magmatic deposits. Ultramafic rocks are the most likely source of nickel since they are nickel-rich (Turekian and Wedepohl, 1961) and host most of the nickel deposits in the study area (see below).

Tectonic Belt

Relative densities of commodity occurrences are discussed by Sinclair, et al., 1977. They are used here to examine relationships between tectonic environment and mineralization as characterized by metals and deposit types.

Relative densities indicate how densities within a particular sub-area (or belt) compare with those of the entire area. The mineral potential for each belt is thereby outlined by abundances of metals and deposit types in the belts. The procedure for determining relative densities is as follows:

1) Individual belt densities are determined by dividing the number of occurrences of each metal or deposit type in each belt by the area (a planimeter measurement) of each belt.

2) Belt densities are divided by those of corresponding metals and deposit types for the entire area.

3) Resulting relative densities are evaluated; those approaching 1.00 (1.90-1.10) are considered average, lower values indicate lower than average densities of occurrences, and higher values indicate a high concentration relative to the entire area.

Table 4-3 is a comparison between Coast Plutonic Belt metal occurrence densities of the present study area and those of the British Columbia Cordillera.[2] Values for many metals from the present study are two to three times greater primarily because all metals in each deposit were counted in this study, whereas Sinclair, et al., 1977, counted only the first-reported metal. On this basis, the densities of copper, molybdenum and tungsten occurrences in this study are probably representative of the entire Cordillera, whereas cobalt, nickel, arsenic, silver, lead and especially zinc occurrences are much denser; density values of antimony and gold are relatively low in the study area.

Factors which might lead to distorted values include cover materials and exploration density. Alluvial deposits (i.e., Fraser River delta) and significant bodies of water (i.e., Howe Sound, Harrison Lake) have been

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[2] The Coast Plutonic Belt of the British Columbia Cordillera includes the entire study area except the Eagle Plutonic Belt, therefore the area of the Spuzzum Plutonic Belt was included with that of the Coast Plutonic Belt in calculating densities for the present study area which appear on Table 4-3. The Cascade Belt (Figure 1-1) was also included in calculations of the British Columbia Cordillera, but its effect is assumed to be minimal.

TABLE 4-3. COMPARISON OF COAST PLUTONIC BELT DENSITIES OF THE PRESENT STUDY AREA AND OF THE CORDILLERA OF BRITISH COLUMBIA[1]

	Number of deposits; present study	Deposits/1,000 Km^2 present study	Deposits/1,000 Km^2 B.C. Cordillera	Present study/ B.C. Cordillera
Co	2	.12	.03	4.0
Ni	12	.70	.11	6.4
Cu	106	6.21	2.20	2.8
Zn	38	2.23	.17	13.4
As	1	.06	.01	6.0
Mo	25	1.46	.52	2.8
Ag	44	2.58	.55	4.7
Sb	2	.12	.10	1.2
W	4	.23	.07	3.3
Au	38	2.23	2.05	1.1
Pb	17	1.00	.21	4.8

[1]Cordilleran values are from Sinclair, *et al.*, 1977.

excluded from areal calculations; remaining glacial and alluvial cover is not believed by the writer to be significant in affecting calculations (cf. Sinclair, et al., 1977). The only major item not considered is forest cover; it undoubtedly varies between belts, but is not dealt with easily.

Density of exploration could distort values because the northern one-third of the area is not easily accessible except for roads along the Fraser River and between Squamish and Pemberton. The Coast and Spuzzum Plutonic Belts are probably the most affected by poor access, but prevailing opinions that plutonic terranes have low mineral potential have also contributed to low occurrence densities in these belts.[3] To check if low density values in plutonic terranes are real, the Coast and Spuzzum Plutonic Belts were subdivided into areas underlain by plutonic rocks and areas underlain by pendant rocks. Resulting density values for the Coast Plutonic Belt are commonly high in pendant rocks and low in plutonic rocks, suggesting that perhaps densities are reflections of both exploration and mineral potential. Values for the Spuzzum Plutonic Belt are consistently low, with the exception of nickel and magmatic values for intrusive rocks. It is possible that low densities reflect poor exploration here, but mineral potential is also expected to be low, as discussed below.

Separate examination of each tectonic belt serves to describe each in terms of metals and deposit types which characterize it; density distributions of individual metals and deposit types can then be studied to examine the behavior of each metal and deposit type across the area. Figures 4-5a,b and 4-6a,b show that intrusions of the Coast Plutonic Complex have a marked dilution effect of density calculations. The area underlain by plutonic rocks with little or no reported mineralization makes up such a

[3]The fact that a good portion of the Coast Plutonic Belt as close as 20 miles to Vancouver has not been mapped in any detail also has not encouraged prospecting.

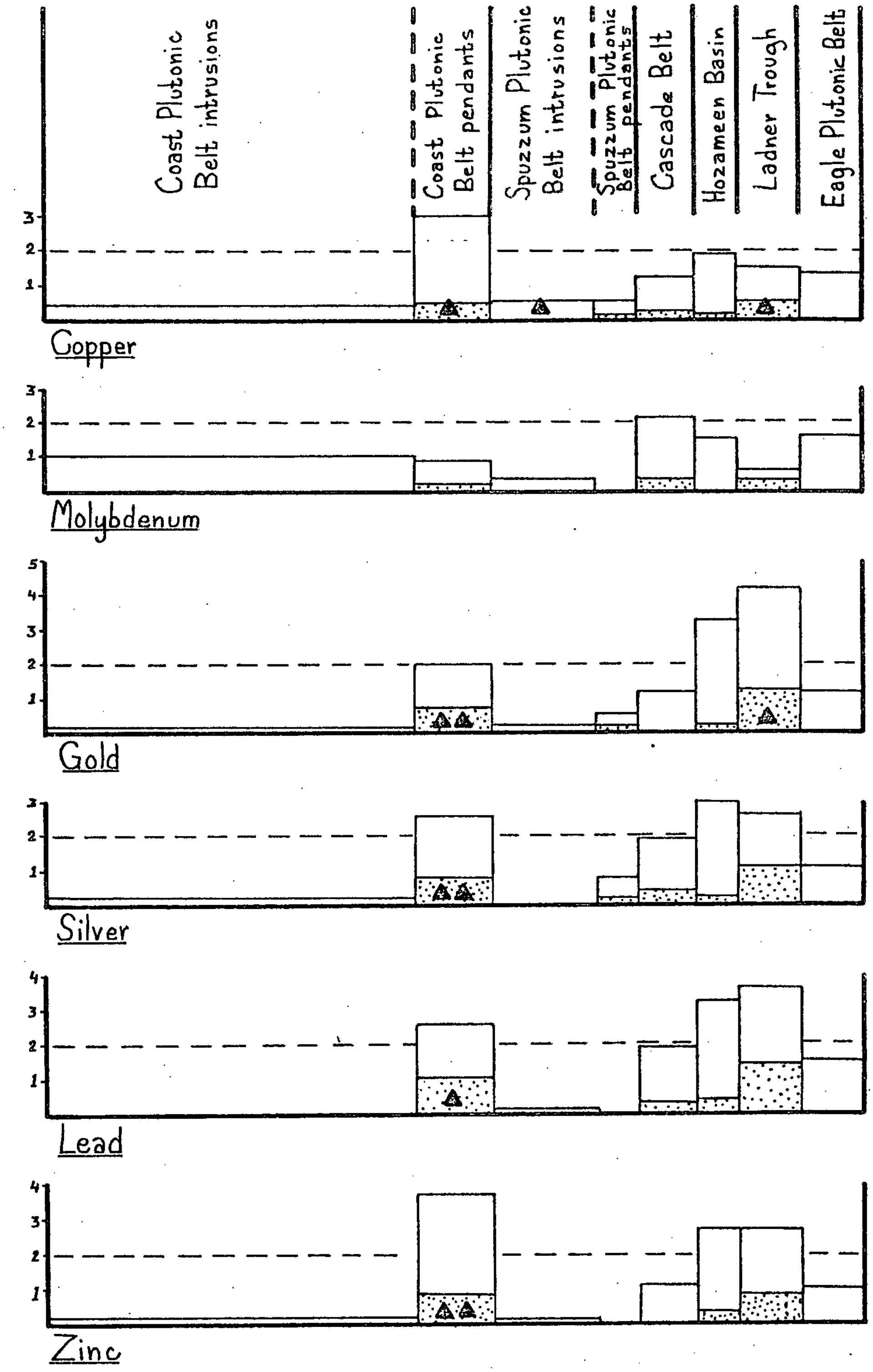

Figure 4-5a. Relative densities of copper, molybdenum, gold, silver, lead and zinc with respect to tectonic belts and subdivisions. Bar widths are proportional to belt areas. Only relative densities greater than two (dashed line) are considered significant. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

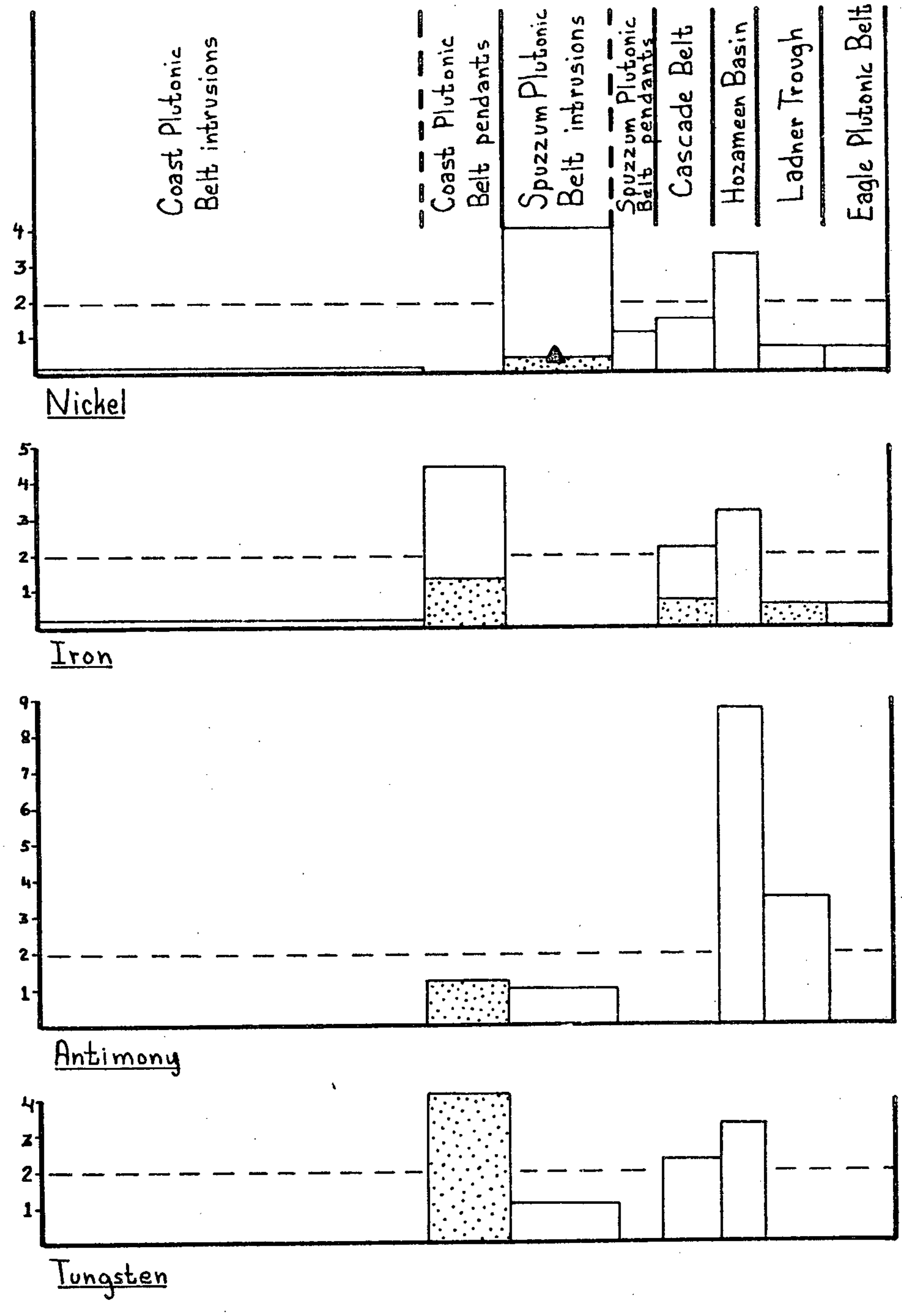

Figure 4-5b. Relative densities of nickel, iron, antimony and tungsten with respect to tectonic belts and subdivisions. Bar widths are proportional to belt areas. Only relative densities greater than two (dashed line) are considered significant. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

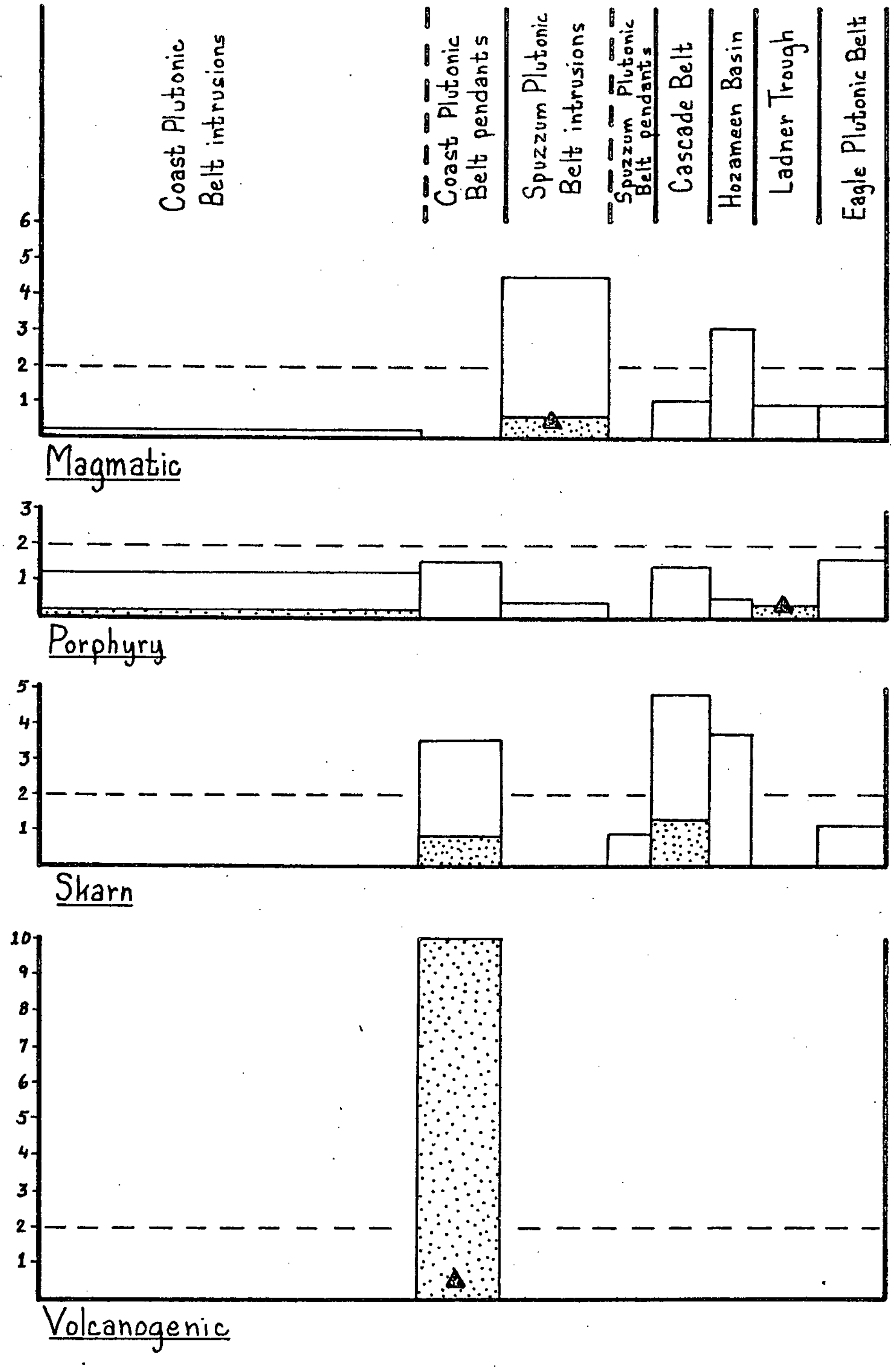

Figure 4-6a. Relative densities of magmatic, porphyry, skarn and volcanogenic deposits with respect to tectonic belts and subdivisions. Bar widths are proportional to belt areas. Only relative densities greater than two (dashed line) are considered significant. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

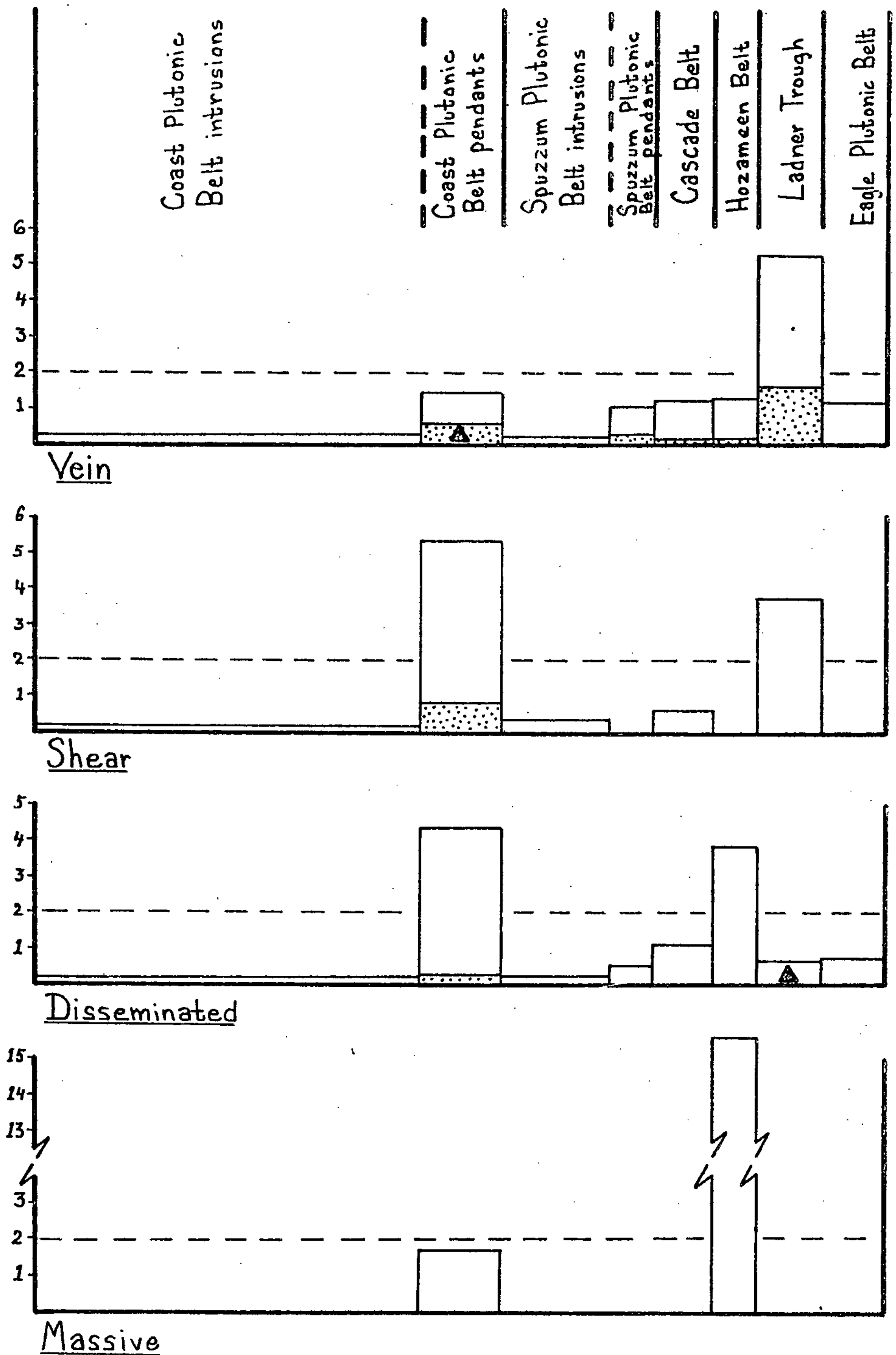

Figure 4-6b. Relative densities of vein, shear, disseminated and massive deposits with respect to tectonic belts and subdivisions. Bar widths are proportional to belt areas. Only relative densities greater than two (dashed line) are considered significant. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

large portion of the study area that all belts without significant plutonism appear heavily mineralized in comparison. Since this is considered an important outcome of relative density calculations, values have not been recalculated to compensate. An alternative approach has been to regard as significant only those values approaching or exceeding an arbitrarily chosen value of 2.00.

A metal or deposit type which is reported rarely will produce an extremely high relative density value for the units in which it occurs; a difference of one or two samples will cause an unrealistic variation in values. Such extreme cases include the following commodities and deposit types (numbers in parentheses are numbers of occurrences); uranium (1), cadmium (1), cobalt (2), bismuth (2), arsenic (3), tungsten (6), antimony (7), volcanogenic (2), and massive (5). Relative densities are not considered for the foregoing categories except as indicators of the presence of a metal or deposit type; uranium, cadmium, cobalt, bismuth and arsenic are not discussed further.

Mineralization Characterizing Tectonic Belts

Table 4-4 summarizes information derived from histograms of Figures 4-5a,b and 4-6a,b by characterizing each tectonic belt according to metals, deposit types and numbers of major deposits.

The Hozameen Basin and Coast Plutonic Belt pendants have the highest potential for the greatest variety of metals and deposit types, but the concentration of producers and major deposits in Coast Plutonic Belt pendants shows a much greater potential for large, producing deposits. The Ladner Trough also exhibits a variety of metal concentrations mainly in veins and (associated?) shears; the number of producers here is almost as high as in Coast Plutonic Belt pendants.

TABLE 4-4. CHARACTERIZATION OF TECTONIC BELTS

Tectonic Belt	Metals	Deposit Type(s)	Major Deposits
Coast Plutonic Belt intrusions	-	-	-
Coast Plutonic Belt pendant rocks	Fe,Zn,Cu,Ag,Pb (Au)[1]	shear, disseminated, skarn (volcanogenic)[2]	2
Spuzzum Plutonic Belt intrusions	Ni	magmatic	1
Spuzzum Plutonic Belt pendant rocks	-	-	-
Cascade Belt	(Fe,Mo,Ag,Pb)	skarn	-
Hozameen Basin	Ni,Au,Pb,Fe,Ag,Zn (Cu)	disseminated, skarn, magmatic (massive)	-
Ladner Trough	Au,Pb,Zn,Ag	vein, shear	2
Eagle Plutonic Belt	-	-	-

[1]Relative densities of metals in parentheses are nearly 2.00; other values are greater than 2.50.

[2]Deposit types in parentheses have very high relative densities based on very few occurrences.

With the exception of relatively abundant magmatic nickel in intrusions of the Spuzzum Plutonic Belt, this subdivision, plus Coast Plutonic Belt intrusions, Spuzzum Plutonic Belt pendants, and the Eagle Plutonic Belt, feature low relative densities which are to be expected in dominantly plutonic or highly metamorphosed terranes.

The Cascade Belt exhibits moderate relative metal occurrence densities; no metal values greatly exceed 2.00. Skarns overshadow all other types of deposits. Perhaps intense deformation is partially responsible for relatively low values in this belt.

Distribution of Metals and Deposit Types among Tectonic Belts

In the preceding section an overall pattern was determined which distinguished the Coast Plutonic Belt pendants, the Ladner Trough and the Hozameen Basin as areas of most abundant mineral occurrences. The Cascade Belt contains moderate occurrence densities, and the remaining plutonic and metamorphic belts have relatively low occurrence densities. A few of the common metals (gold, lead, zinc, silver; Figure 4-5a) exhibit similar distributions which reflect this pattern of abundance. Minor variations are as follows: gold and lead are more common in the Hozameen Basin and Ladner Trough than in pendants of the Coast Plutonic Belt, but zinc shows the opposite relations; silver is almost equally abundant in all three areas. The behavior of these metals suggests that tectonic environment was not very selective between them. In other words, both precious and base metals occur in approximately the same manner in a variety of tectonic environments.

Iron oxide and tungsten (Figure 4-5b) behave much like zinc except that both are notably low or absent from the Ladner Trough. Copper is most common in Coast Plutonic Belt pendants, and is only slightly enriched in the Hozameen Basin. Antimony is reported most commonly in the Hozameen Basin or Ladner Trough and is reported rarely in Coast Plutonic Belt pendants.

Molybdenum is not notably abundant in any belt. Relative abundances of nickel show significantly high values in Spuzzum Plutonic Belt intrusions and the Hozameen Basin.

Tectonic belts show greater correlation with deposit types (Figures 4-6a,b). Vein, volcanogenic and massive deposits are particularly abundant in the Ladner Trough, Coast Plutonic Belt pendants and Hozameen Basin, respectively. Shears, magmatic and disseminated deposits are each common in two belts, and skarns are common in three. Porphyry deposits show no significant concentration in any belt.

Host Rock Formation

Figure 4-7 records the total number of deposits reported in each mineralized unit of the study area; the Ladner, Hozameen and Gambier Groups, and the Harrison Lake Formation stand out as the best-mineralized units.[4] Two major deposits, Aurum (HNW-3) and Canam (HSW-1), and many producers in the Ladner Group lend even more importance to it as a host for mineralization. Considering the many occurrences in the Hozameen Group, the lack of major deposits is notable. The Gambier and Gambier? Groups together account for an abundance of mineralization (on all scales) exceeding that of the Ladner Group; therefore, the Gambier? Group pendants are worthy of close examination. Like the Hozameen Group, the Harrison Lake Formation has yet to produce a major deposit, but unlike the Hozameen Group, mineralization in the Harrison Lake Formation has warranted considerable recent attention. Major mineralization in the Giant Mascot Ultramafite is not only a unique occurrence in the study area, but also among ultramafic-hosted mineral deposits throughout the world (Naldrett, 1973).

[4]The area underlain by Coast Plutonic intrusions is so large that even uncommon mineralization can amount to a large number of deposits which will, consequently, overshadow all other units when compared on a scale of total occurrences. High numbers of occurrences in some non-plutonic units may also be reflections of areal abundance.

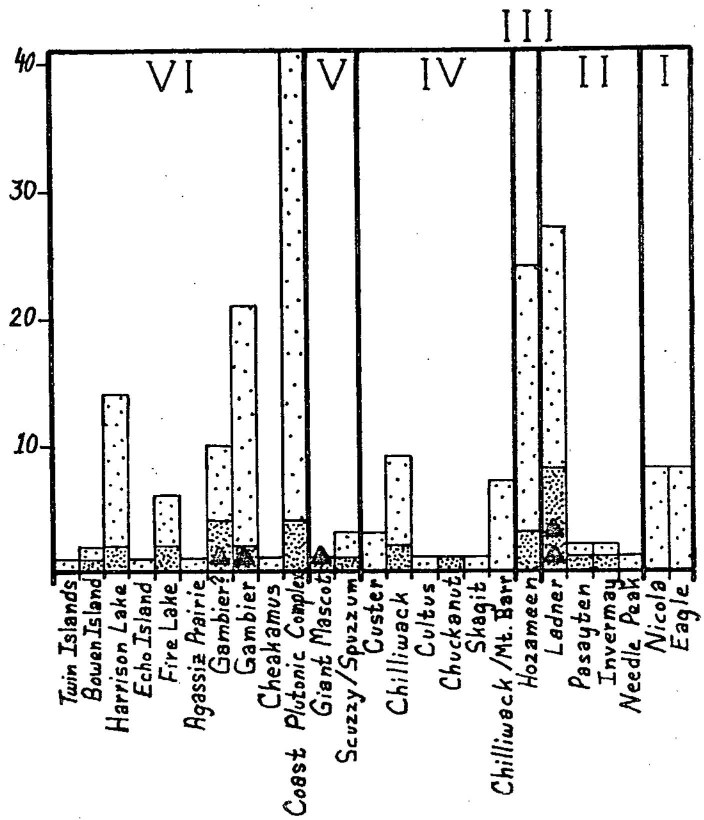

Figure 4-7. Total number of occurrences in each mineralized geologic unit of the study area (host units are known for 77% of all deposits in the study area). Roman numerals identify tectonic belts (see Table 2-1). Triangles identify major deposits of Table 4-1; dense stipples represent deposits with production records; sparse stipples represent showings, prospects and developed prospects.

Distribution of Deposit Types and Metals Among Host Rock Formations

The distribution of individual metals and deposit types among host rock formations (Figures 4-8 and 4-9a,b) are significant only if they differ from that of total deposits (Figure 4-7).

The abundant mineralization in the Ladner Group is a reflection of vein deposits; other deposit types do not exhibit this degree of prominence in any particular formation. The presence of shears in the Gambier Group, disseminated deposits in the Harrison Lake Formation, porphyries in the Coast Plutonic Complex, and the apparent absence of volcanogenic deposits in units other than those of Coast Plutonic Belt pendants is notable.

The only differences between distribution patterns of total occurrences and of copper occurrences (Figure 4-9a) are that less than one half the Ladner Group deposits carry copper values. This is a significantly low value when one considers that 73 percent of the deposits in the study area contain copper. A major copper deposit, Canam (HSW-1), in the Ladner Group stands out almost as a contradiction to these relatively low copper values.

Gold and silver behave similarly, both reflecting total abundances shown in Figure 4-7, with minor exceptions. Coast Plutonic Belt intrusions show very low values for both, and gold occurrences are slightly more abundant in the Hozameen and Ladner Groups than are those of silver, which in turn are more common than gold in the Cascade Belt.

The major distinction between lead and zinc (Figure 4-9b) is that lead is minor in Coast Plutonic Belt pendants, but zinc is relatively abundant. Both metals are uncommon in Coast Plutonic Belt intrusions, but are abundant in both the Hozameen and Ladner Groups.

The distribution of molybdenum mirrors that of porphyry deposits, but although molybdenum occurrences are more abundant than any other metal in Coast Plutonic Belt intrusions, the density of these occurrences is not high.

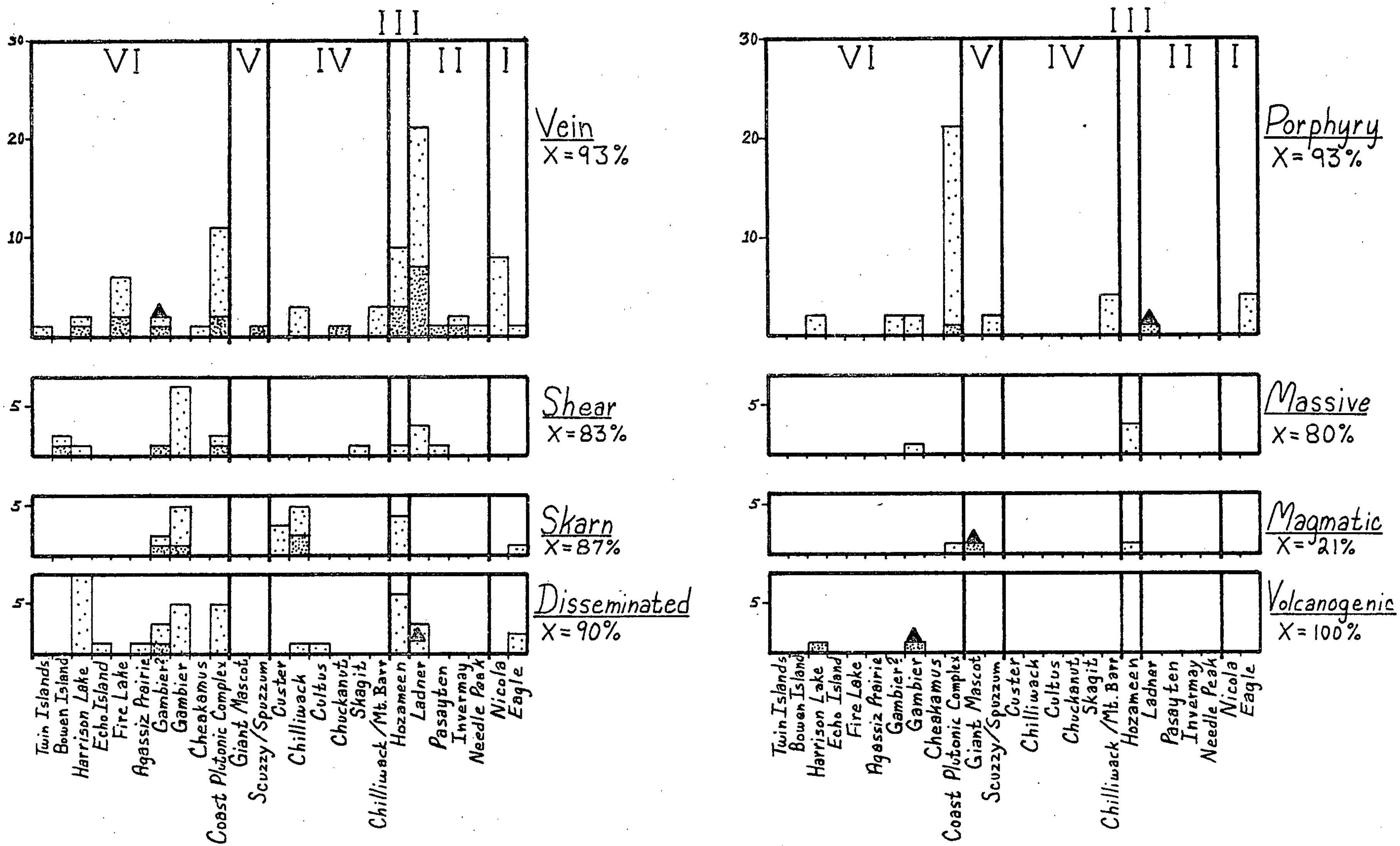

Figure 4-8. Number of occurrences of each deposit type with respect to host rock unit. "X" is the percent of total deposits of each deposit type for which host rock unit is known. Roman numerals identify tectonic belts (see Table 2-1). Triangles identify major deposits of Table 4-1; dense stipples represent deposits with production records; sparse stipples represent showings, prospects and developed prospects.

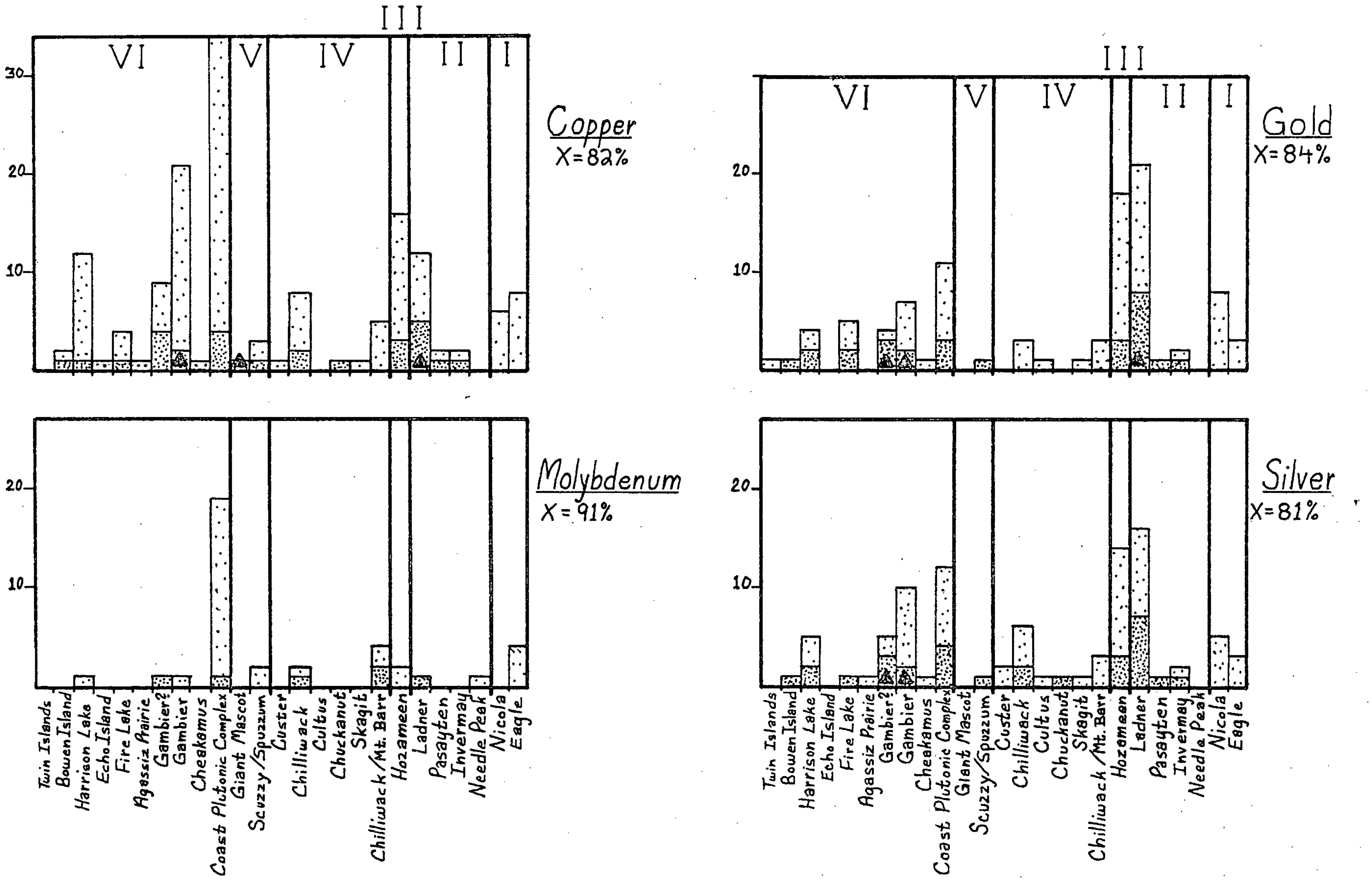

Figure 4-9a. Number of occurrences of copper, molybdenum, gold and silver with respect to host rock unit. "X" is the percent of total deposits of each metal for which host rock unit is known. Roman numerals identify tectonic belts (see Table 2-1). Triangles identify major deposits of Table 4-1; dense stipples represent deposits with production records; sparse stipples represent showings, prospects and developed prospects.

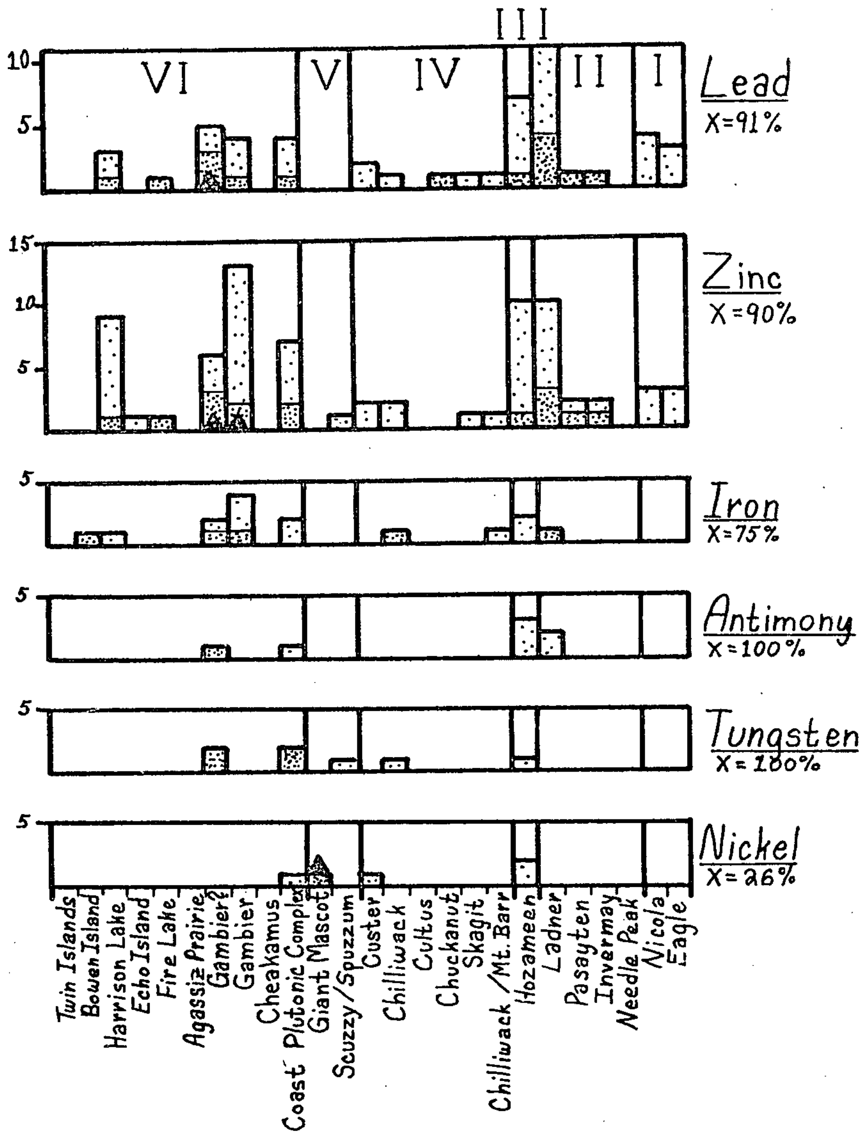

Figure 4-9b. Number of occurrences of lead, zinc, iron, antimony, tungsten and nickel with respect to host rock unit. "X" is the percent of total deposits of each metal for which host rock unit is known. Roman numerals identify tectonic belts (see Table 2-1). Triangles identify major deposits of Table 4-1; dense stipples represent deposits with production records; sparse stipples represent showings, prospects and developed prospects.

Mineralization Characterizing Host Rock Formations

Host rock formations are discussed as members of the tectonic belts in which they occur, thereby further clarifying occurrence distributions within tectonic belts. Figure 4-7 serves as an outline for discussion of relative abundances between formations. Figures 4-8 and 4-9a,b provide information on the more weakly mineralized units not discussed in detail below.

Eagle Plutonic Belt. Deposits in the Eagle Plutonic Belt occur in both the Nicola Group and the Eagle Complex (Figure 4-10a); no production has been recorded in this belt. Considering the 99 percent dominance of plutonic outcrop over volcanic (Nicola) outcrop, the fact that the number of occurrences are equal in both units suggests that the Nicola Group is well-mineralized. In fact, mineralization on the Princeton Map Sheet (92H, East Half) is reported to occur most commonly in the Nicola Group (Rice, 1960).

Only veins are reported in the Nicola Group in the study area, five of them in the Jim Kelly Creek Camp, whereas the Eagle Complex contains four different deposit types dominated by porphyries. Recognized metals do not vary much between units, but Nicola Group veins contain more gold, and porphyries in the Eagle Complex contain molybdenum mineralization not found in the Nicola Group.

Ladner Trough. Of the seven[5] formations in the Ladner Trough, only the Ladner Group (Figure 4-10a) contains abundant mineral occurrences; the Pasayten Group, Needle Peak Pluton and Invermay Stock contain few deposits.

The Ladner Group is dominated by veins of the Ladner Gold Belt and Summit Camp, one-third of which are producers. However, the two major deposits, Canam (HSW-1) and Aurum (HNW-3), are porphyry and disseminated

[5]Only six units are recognized on the time-space plot (Figure 2-2), but a small mineralized pluton, the Invermay stock, is an additional unit considered in this discussion. The age of this stock is probably equivalent to the 84 Ma pluton two kilometers north, which straddles the Hozameen Fault.

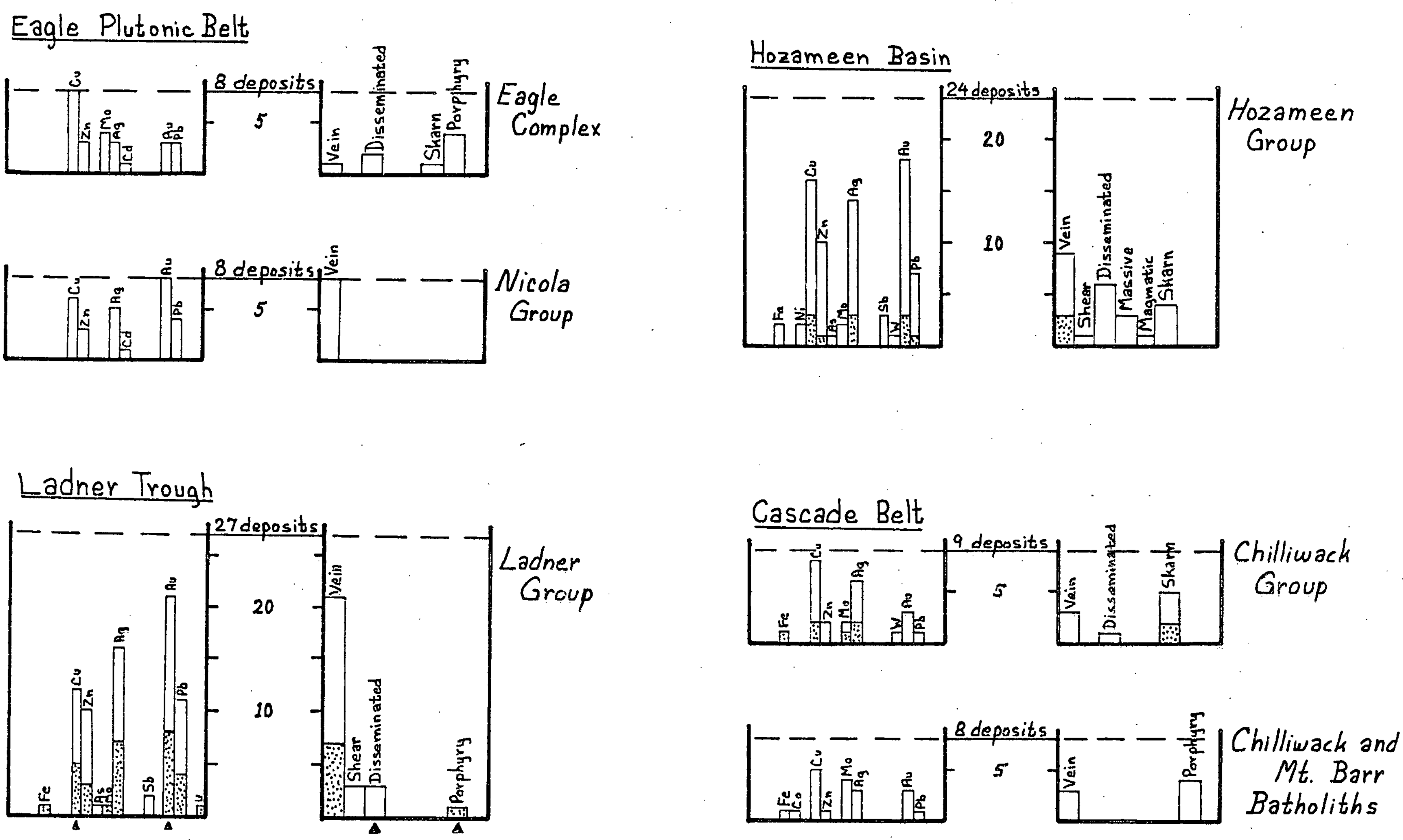

Figure 4-10a. Number of occurrences in host rock units of the Eagle Plutonic Belt, Ladner Trough, Hozameen Basin and Cascade Belt, with respect to metal content and deposit type. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

types, respectively. Precious metal occurrences are more dominant than base metals, and the only uranium occurrence in the area is found here (Canam).

Hozameen Basin. Deposits in the Hozameen Basin occur in the abundant Hozameen Group (Figure 4-10a). A variety of deposit types is present, concentrated in the 10-Mile and 23-Mile Creek Camps; veins are only slightly more common than other types. The most commonly reported metal is gold, but copper and silver are almost as common; zinc and lead are also reported with moderate frequence. The only production was from veins.

Cascade Belt. Mineral occurrences are most common in the Chilliwack and Mt. Barr batholiths, and the Chilliwack Group (Figure 4-10a). Other formations with few occurrences are Custer Gneiss, Cultus, Chuckanut and Skagit Formations.

The Chilliwack and Mt. Barr batholiths are grouped together because they are similar in age, setting and mineralization. Deposits are either veins or porphyries; metals are copper, molybdenum, silver and gold. Skarns characterize the Chilliwack Group; copper and silver stand out as the most common metals. Minor production in the Cascade Belt is restricted to the Chilliwack Group and Chuckanut Formation.

Spuzzum Plutonic Belt. Mineralized units of this belt are the Scuzzy and Spuzzum plutons, and the Giant Mascot Ultramafite. Although the number of deposits is small, the magmatic nickel-copper orebodies of the Giant Mascot Ultramafite form one of the major deposits in the study area (HSW-4).

Coast Plutonic Belt. The Twin Islands and Bowen Island Groups, and Echo Island, Agassiz Prairie and Cheakamus Formations contain very few deposits. Figure 4-10b illustrates mineralization in the five formations

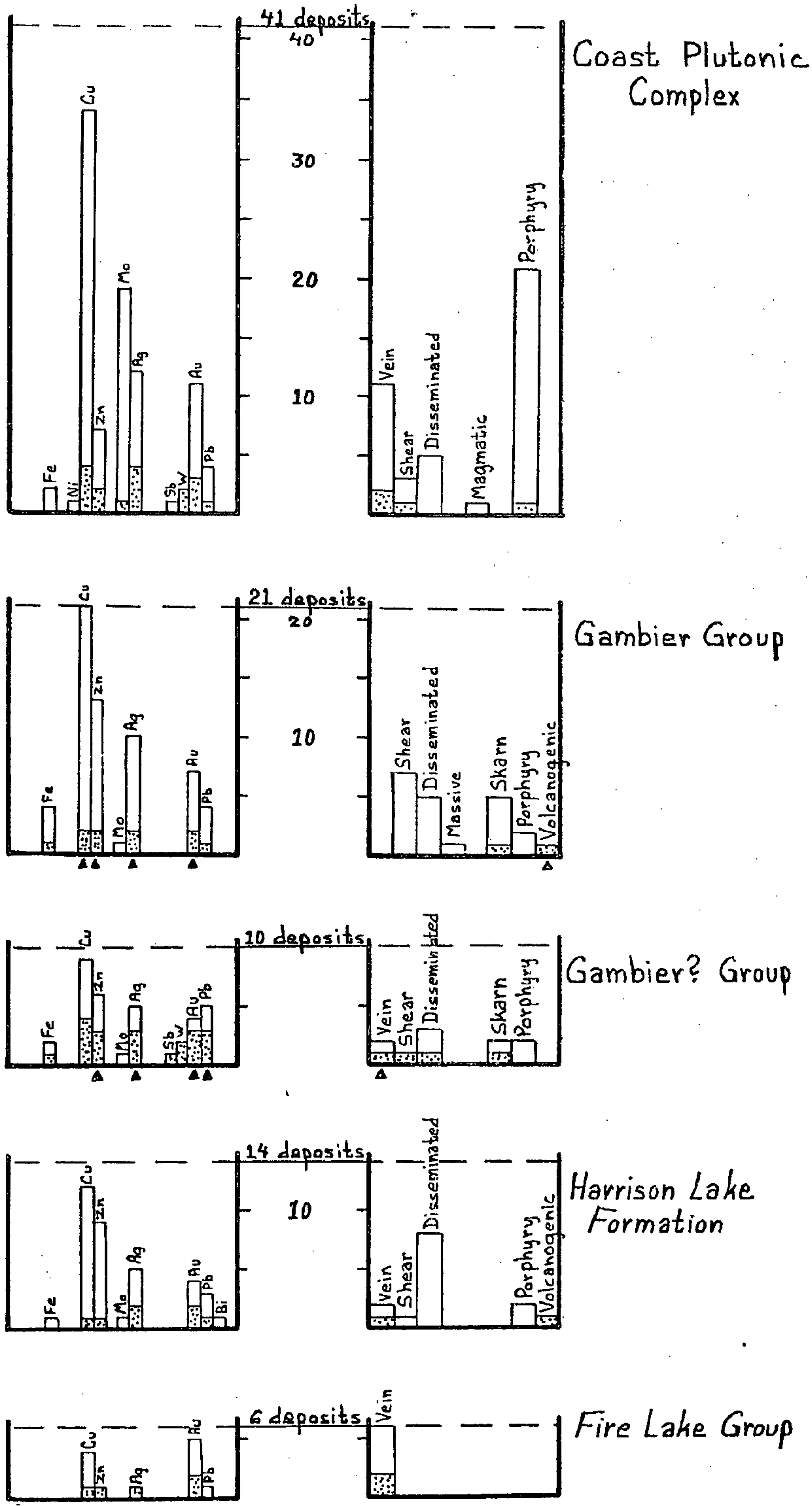

Figure 4-10b. Number of occurrences in host rock units of the Coast Plutonic Belt with respect to metal content and deposit type. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

discussed below.

The Fire Lake Group contains only gold-copper veins in the Fire Lake Camp, but other units are more diversified in their deposit content. Mineralization in the Harrison Lake Formation most commonly is disseminated, but minor production was from a vein and a volcanogenic deposit (Providence, HNW-2, and Seneca, HSW-13, respectively). Copper and zinc dominate other metals, although silver, gold and lead also occur.

The Gambier Group is divided into two sections because the two mineralized pendants to the north (referred to as "Gambier? Group") have not been correlated positively with the Gambier Group. The number of producers in the southern pendants is very low, but includes the major volcanogenic deposit at Britannia (G-3), whose presence alone classifies its host as the best mineralized unit in the entire study area. Vein deposits, which dominate the area in number, are not reported from the Gambier Group in the south. As little as ten years ago, this would not have been the case, as Britannia was then considered a vein. It is possible that other deposit types (except porphyries) might be volcanogenic accumulations (especially McVicar, G-6) which have not yet been recognized as such. Copper is by far the most commonly reported metal; zinc and silver also are reported frequently.

One or both of the northern pendants may be Triassic or Jurassic, as discussed in the previous chapter. The percentage of producers is high, and one vein deposit is major (Northair, J-130). Metal distributions resemble those of Gambier Group pendants discussed above except for the more abundant occurrence of lead and the presence of antimony and tungsten.

Porphyries are the most common deposits in intrusions of the Coast Plutonic Complex; this is reflected in metal distributions by dominant copper and molybdenum. Moderate silver and gold reports are probably from vein deposits which are the only other relatively common type of mineralization. Production is low.

Host Rock Type

Host rock types are known for 78 percent of the deposits in the study area. Intrusive, volcanic and sedimentary rocks are well-represented, but metamorphic rocks are not discussed for two reasons:

1) Only 15 deposits (out of 203 total) report metamorphic host rocks; and

2) Eight of those 15 occurrences are described as metavolcanic or metasedimentary, and can therefore be classed as volcanic or sedimentary.

If a metal or type of deposit is associated genetically with a particular rock type, it should be readily apparent, regardless of coincidental occurrences in other types. Therefore, when more than one mineralized rock type is reported for a deposit, each is recorded and given equal weight.

The three major rock types are subdivided further as follows:

1) Intrusive rocks which include[6]
   a) intermediate to acid intrusions,
   b) ultramafic intrusions, and
   c) dikes of any composition.

2) Volcanic rocks which include
   a) basic volcanic rocks and greenstones (i.e., andesite, basalt),
   b) acid volcanic rocks (i.e., rhyolite, dacite),
   c) pyroclastic volcanic rocks (i.e., tuff, agglomerate, breccia) of unspecified composition,[7] and
   d) unclassified volcanic and metavolcanic rocks.

3) Sedimentary rocks which include
   a) clastic sedimentary rocks (i.e., shale, sandstone, conglomerate, breccia),
   b) limestone, and
   c) siliceous (i.e., chert, quartzite) and unclassified sedimentary rocks.

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[6]With the exception of dikes, mafic intrusions were not reported to host mineralization in the study area.

[7]A pyroclastic rock whose composition is known is categorized by that composition.

Metals and deposit types are first examined below to review their distribution among the three major rock types (Figure 4-11). All histogram distributions in this section are compared to mineralized rock type abundances for the study area shown in Figure 4-12. The apparent concentration of mineral occurrences in intrusive rocks is misleading, because the amount of plutonic outcrop is much greater than either volcanic or sedimentary outcrop.[8] If densities of occurrences were determined for each rock type, values for plutonic rocks would be very low; volcanic and sedimentary rocks (especially basic volcanic rocks and clastic sedimentary rocks, Figures 4-14 and 4-15) would exhibit very high densities.

Subsequent discussion of rock types uses the more detailed classifications described above to characterize mineralization in each host rock and further examine the behavior of metals and deposit types in the smaller categories. Figures 4-2 and 4-3 are used as indicators of general abundances for comparison of mineralization in each rock type.

Distribution of Metals and Deposit Types Among Host Rock Types

Copper, molybdenum and nickel exhibit predictable distribution patterns (Figure 4-11). Copper occurrences are abundant in every rock type, but nickel and molybdenum occurrences are associated preferentially with intrusive rocks; other metals studied appear to occur preferentially in volcanic and sedimentary rocks.

Zinc, lead and antimony occurrences prefer volcanic over sedimentary rocks, zinc showing the most significant preference. Gold, silver and iron oxides are more common in sedimentary than volcanic rocks.

Many vein occurrences are reported in all rock types, but the density

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[8] Sixty-four percent of the study area is underlain by Eagle Complex, Coast Plutonic Belt intrusions and Spuzzum Plutonic Belt intrusions; the remaining 36 percent is occupied by both volcanic and sedimentary rocks, along with various plutons whose areas were not computed.

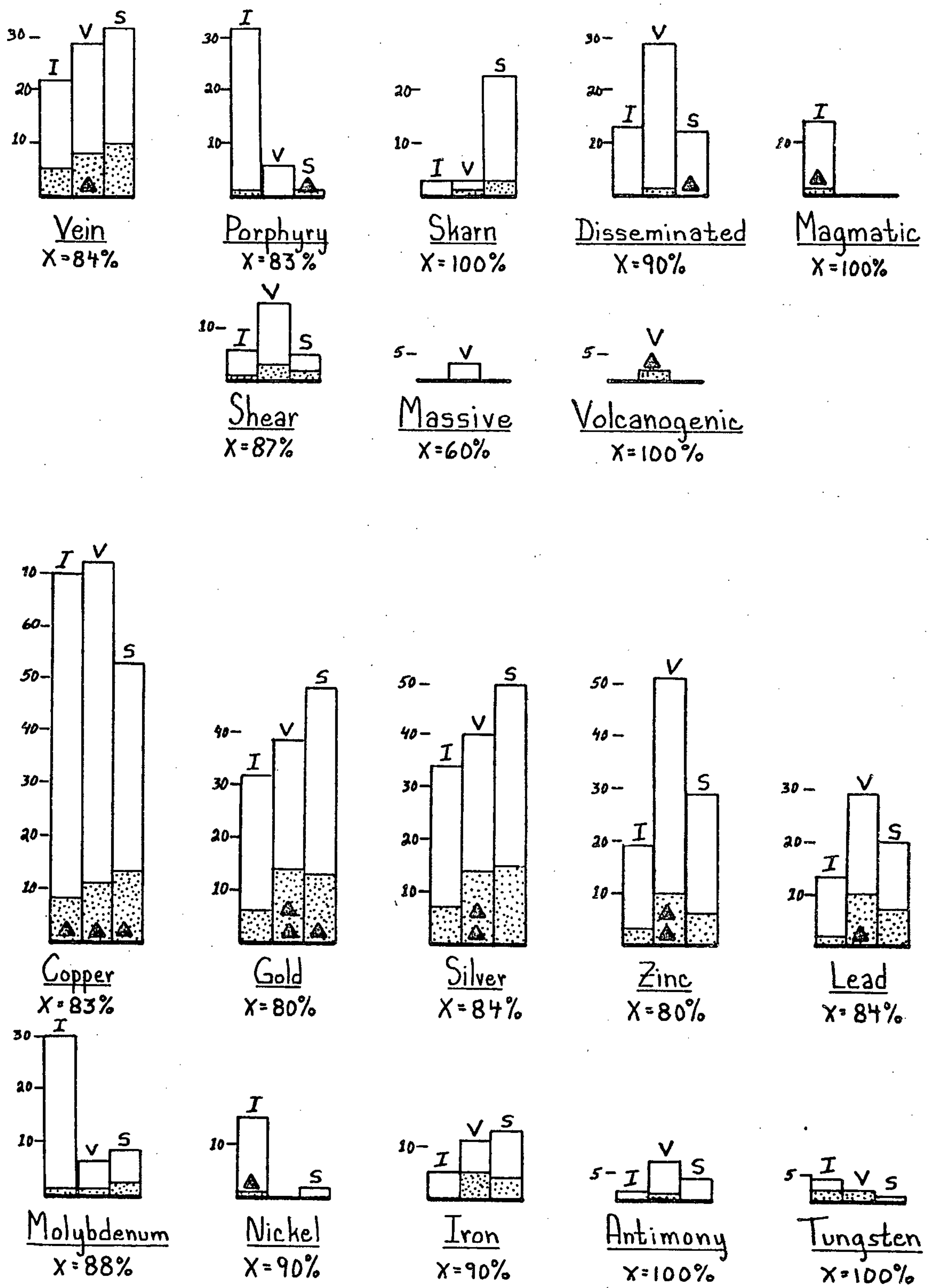


Figure 4-11. Number of occurrences of each metal and deposit type with respect to intrusive (I), volcanic (V) and sedimentary (S) host rock types. "X" is the percent of total deposits of each metal or deposit type for which host rock type is known. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

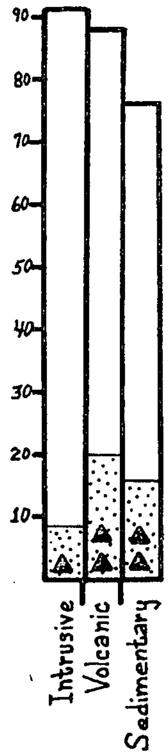


Figure 4-12. Total number of occurrences in intrusive, volcanic and sedimentary host rocks (host rock type is known for 73% of all deposits in the study area). Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

of occurrences in intrusive rocks is very low. Sedimentary rocks favor vein mineralization slightly more than volcanic rocks, but the latter host the only major vein deposit, Northair (J-130).

Porphyry and Magmatic deposits are particularly abundant in their genetically associated intrusive host rocks. The occurrence of a major porphyry deposit, Canam (HSW-1), in sedimentary rocks is unusual.

A preference by skarn deposits for sedimentary rocks is predictable, as calcareous sedimentary rocks are commonly affected by contact metasomatism.

The fact that the volcanogenic deposits, Britannia (G-3) and Seneca (HSW-13) are in volcanic rocks is almost a matter of definition, although distal sedimentary rocks are also potential hosts. With only two reported deposits of this type, further discussion is not possible. Massive deposits also lack a sufficient data base for detailed analysis.

Shear and disseminated deposits occur in all rock types, but are most common in volcanic rocks: the only disseminated deposit to produce, Astra (J-45), is in volcanic rocks. It is possible that these deposits are genetically related to volcanism, representing syngenetic accumulations. The presence of a major disseminated deposit, Aurum (HNW-3), in sedimentary rocks is unusual.

Mineralization Characterizing Host Rock Types

Figures 4-13 through 4-15 illustrate the distribution of metals and deposit types among specific rock types characterizing intrusive, volcanic and sedimentary rocks. The height of each histogram is equivalent to the number of deposits in each rock type so that values may also be estimated as percentages.

Intrusive Rocks (Figure 4-13). The high percentage of porphyry deposits

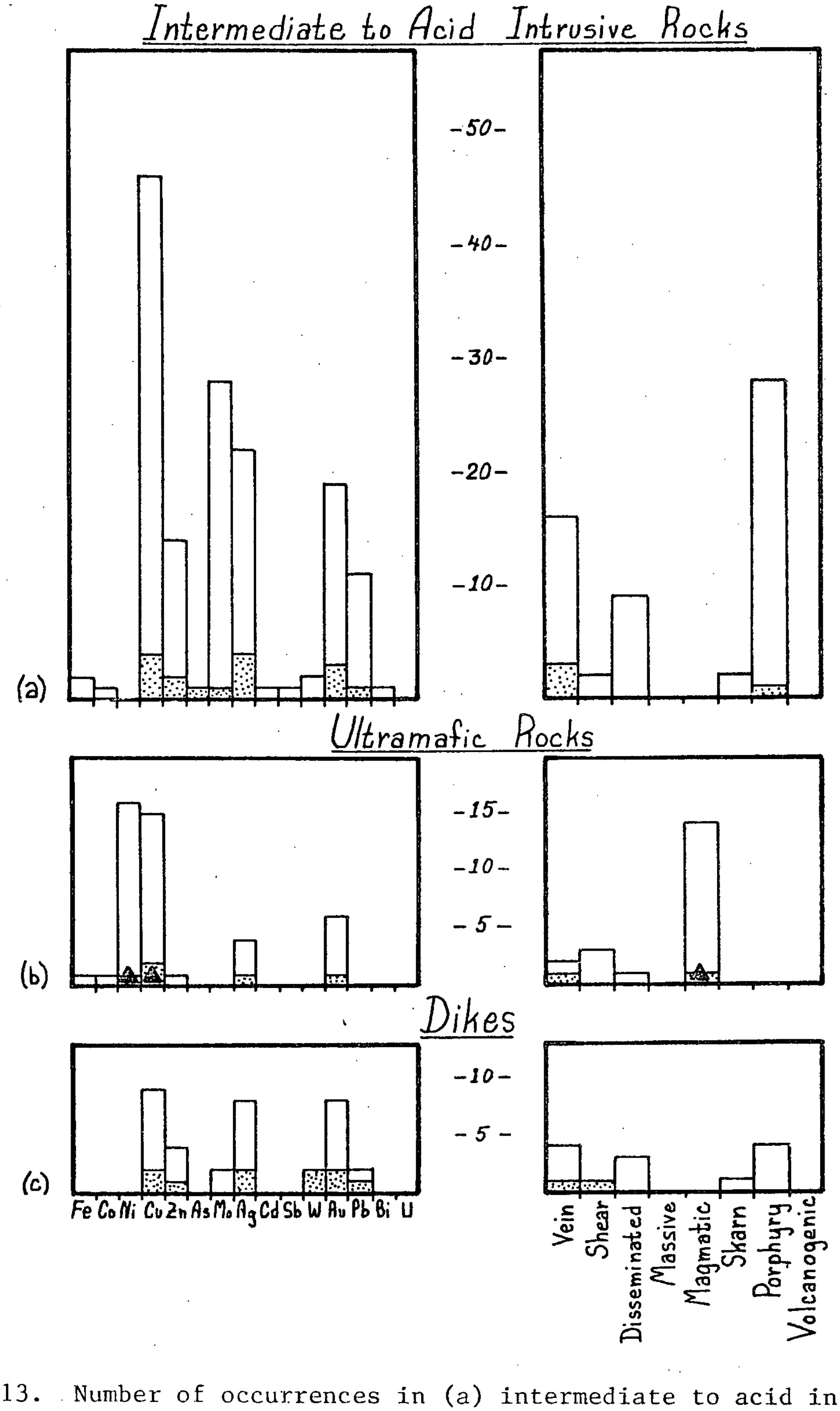


Figure 4-13. Number of occurrences in (a) intermediate to acid intrusive rocks, (b) ultramafic rocks, and (c) dikes, with respect to metal content and deposit type. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects, and developed prospects.

in intermediate to acid intrusive rocks has resulted in an unusually high abundance of molybdenum occurrences in these rocks. Similarly, the high incidence of magmatic deposits in ultramafic rocks correlates directly with the high proportion of nickel occurrences in ultramafic rocks, to the exclusion of all other metals except gold and silver. Vein and disseminated deposits in intermediate to acid intrusive rocks probably carry the variety of metals which is not present in ultramafic rocks.

Occurrences which report dikes as the predominant mineralized host rock most commonly contain copper, gold and/or silver. Dikes do not show a preference for any particular type of deposit.

Volcanic Rocks (Figure 4-14). Metal abundances in basic volcanic rocks resemble general abundances of metals in the study area, except that basic volcanic rocks appear to contain an above average proportion of zinc occurrences and, to a lesser extent, lead. This trend is even more evident in acidic and pyroclastic volcanic rocks where zinc is as common as copper. The number of lead occurrences in this category is close to that of the precious metals; normally lead is only one-half to one-third as common as precious metals. The absence of nickel and few reports of molybdenum in all volcanic rocks is to be expected if concentrations of these metals originate with intrusive rocks. Antimony most often occurs in volcanic (especially basic volcanic) rocks.

Although many veins occur in volcanic rocks, disseminated deposits are as common. The high proportion of deposits reporting vein, shear, disseminated and massive deposits, and the presence of the only recognized volcanogenic deposits in the study area suggest that occurrences in volcanic rocks are dominantly of volcanogenic origin. Veins, disseminations and massive sulfides are characteristic of volcanogenic deposits, and shears might easily describe portions of a deformed volcanogenic deposit. Skarns

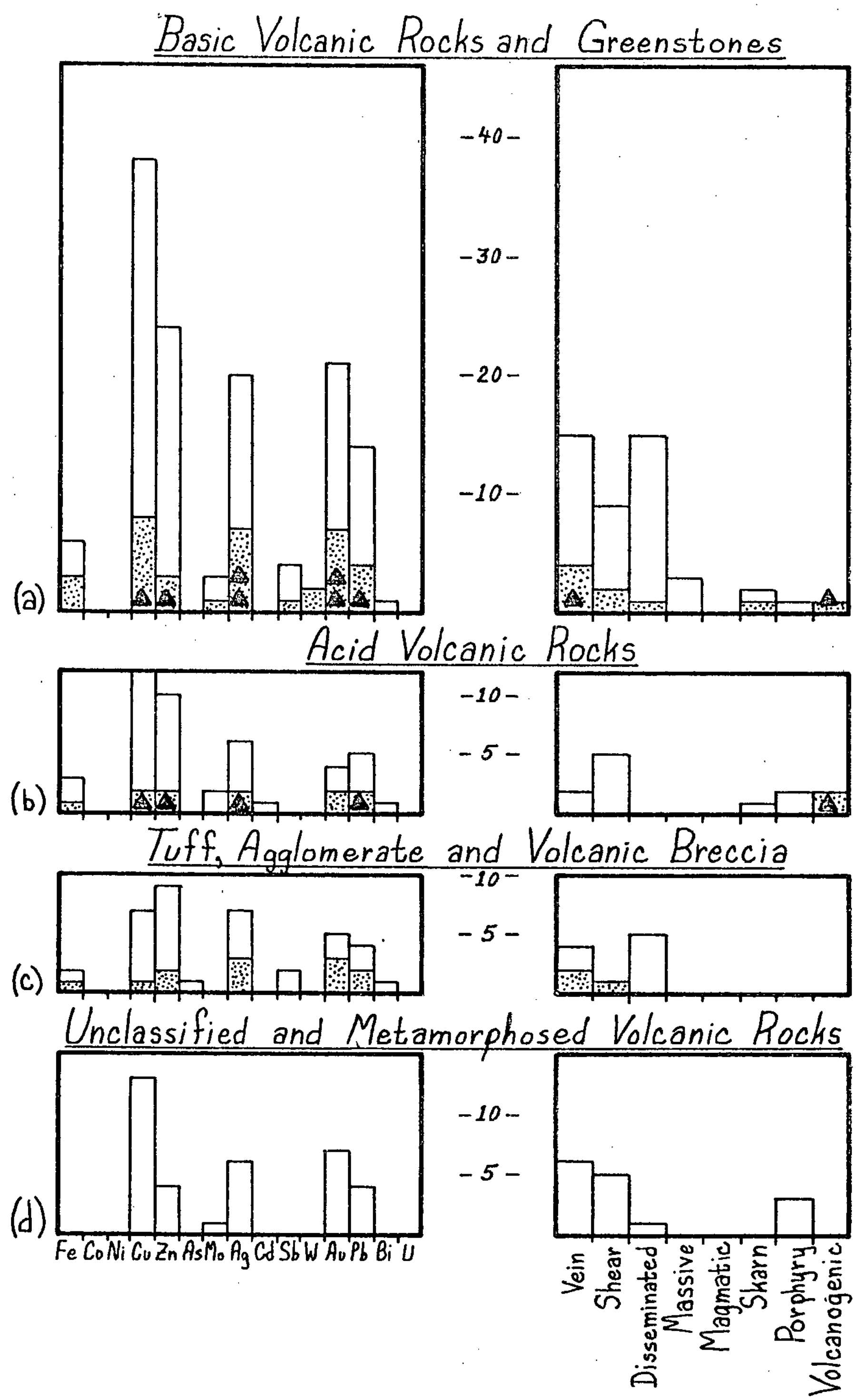


Figure 4-14. Number of occurrences in (a) basic volcanic rocks and greenstones, (b) acid volcanic rocks, (c) tuff, agglomerate and volcanic breccia, and (d) unclassified and metamorphosed volcanic rocks, with respect to metal content and deposit type. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

and porphyry deposits do not appear to favor volcanic rocks.

Sedimentary Rocks (Figure 4-15). Clastic sedimentary rocks report far less copper than intrusive and volcanic rocks, but gold and silver are reported in more than half the deposits. Despite the importance of precious metals to clastic sedimentary rocks, only one major non-producing gold deposit, Aurum (HNW-3), is present (*cf.* the two major producing deposits with precious metals in volcanic rocks; Britannia, G-3, and Northair, J-130).

Other sedimentary rocks, on the other hand, are dominated by copper. With the exception of two nickel occurrences in limestone, nickel and molybdenum are rare. Iron is commonly reported in limestone, and the only uranium occurrence in the area is in clastic sedimentary rocks.

Veins account for 74 percent of all deposits in clastic sedimentary rocks, and many were producers, but disseminated and porphyry types host the two major deposits, Aurum (HNW-3) and Canam (HSW-1). Skarn mineralization exceeds all other types in limestone.

DEPOSIT DISTRIBUTION MAPS

Appendix B contains areal distribution maps of deposit types and selected metals reproduced directly from Calcomp plotter output (*cf.* Sinclair, *et al.*, 1978). Outstanding physiographic features and tectonic belts are included for easy reference to Figure 1-2. Observations of deposit type distributions are as follows:

1) Magmatic deposits are noticeably clustered around Giant Mascot, as discussed previously.

2) Massive deposits (with one exception) are located in the 10-Mile Creek Camp.

3) Shear deposits are clustered a) around Britannia and b) in an area which combines deposits of two dominantly vein camps whose ages of mineralization are probably dissimilar--Summit and Ladner Gold. Shears in the Coast Plutonic Belt

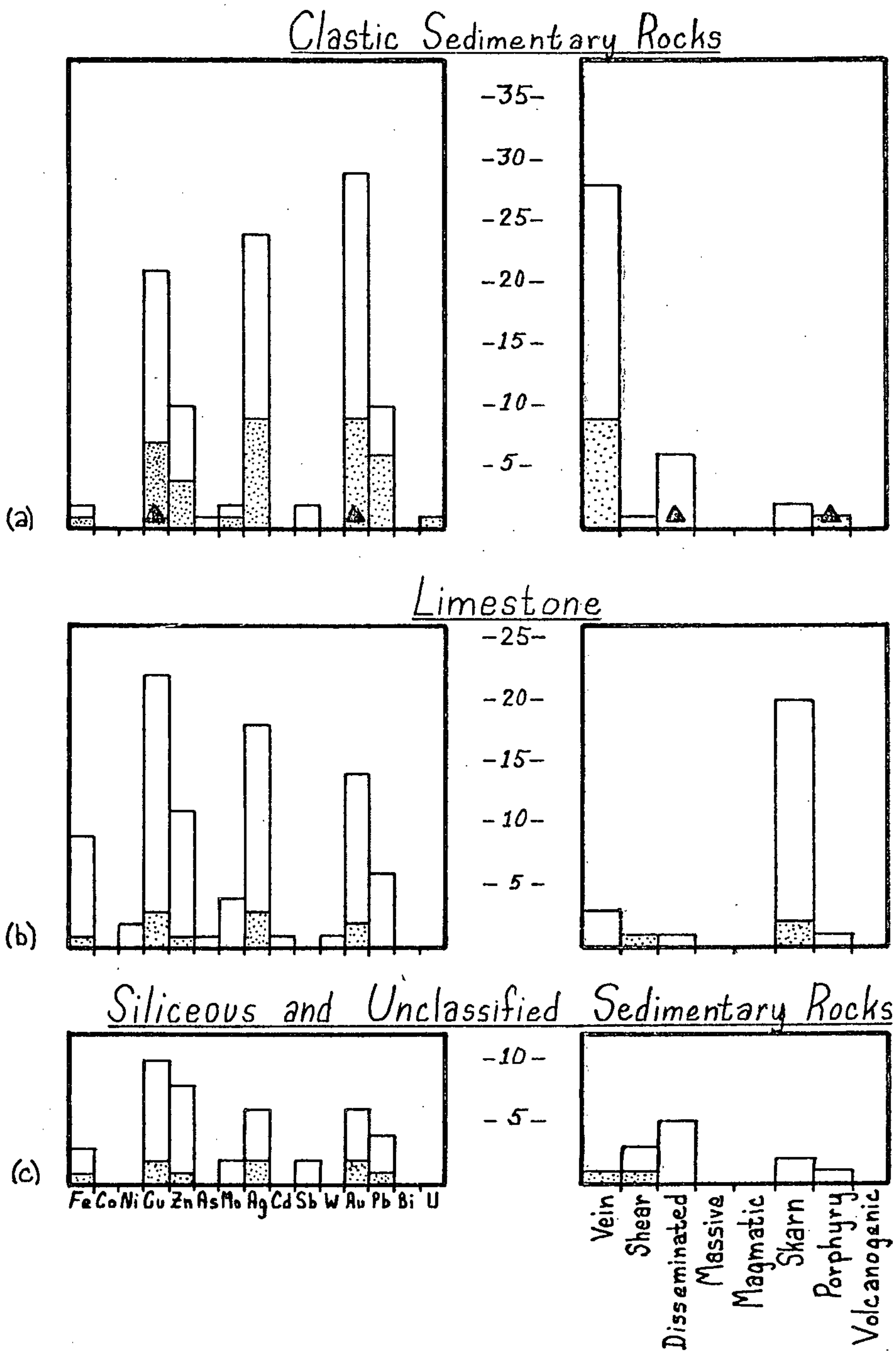


Figure 4-15. Number of occurrences in (a) clastic sedimentary rocks, (b) limestone, and (c) siliceous and unclassified sedimentary rocks, with respect to metal content and deposit type. Triangles identify major deposits of Table 4-1; stipples represent deposits with production records; blank bars represent showings, prospects and developed prospects.

are intimately associated with disseminated and porphyry deposits, whereas the eastern cluster of shears is notably devoid of both disseminated and porphyry occurrences. The opposite relationship applies to shears and veins, as the eastern shear deposits are spatially related to veins which are not reported in the Britannia area.

4) Veins dominate the eastern one-third of the area, but are rarely reported in the Coast Plutonic Belt except at Northair, Fire Lake and Pitt Lake; no veins are reported west of 123° 30' west longitude. Vein deposits are not reported in the vicinity of the known volcanogenic deposits, Britannia and Seneca.

5) Although porphyry deposits are evenly scattered among occurrences in the eastern one-third of the area, they occur in the Coast Plutonic Belt mainly in an east-west-trending band from the Sechelt Peninsula to Harrison Lake. Porphyries are slightly more dense around Britannia than elsewhere. With one exception, no vein deposits occur in this band of porphyries.

6) Disseminated deposits in the Coast Plutonic Belt occur in an arc extending northwest to southeast through Northair, Britannia, Harrison Lake and the 10-Mile Creek Camp; they surround the Seneca deposit.

7) Skarns are most common in the southeast corner of the area, and occur in the Coast Plutonic Belt only near Northair, on the Sechelt Peninsula, and slightly north of Vancouver.

Metals do not generally exhibit distributions as marked as those of deposit types. To the contrary, most metal distributions are similar to that of the general abundance of deposits shown in Figure 1-2, with minor deviations. Some observations that can be made are as follows:

1) The distribution of nickel is similar to that of magmatic deposits. The cluster of nickel deposits is devoid of zinc, silver, gold, lead and molybdenum occurrences.

2) The distribution of molybdenum is similar to that of porphyries. Only one deposit contains both molybdenum and lead, Canam (HSW-1).

3) Copper, silver, gold and zinc are distributed according to the general abundance of deposits, only gold exhibiting a marked preference to eastern deposits.

4) Lead is reported primarily in the southeastern corner of the area and less commonly in the Northair District. Only scattered occurrences appear elsewhere, and no lead occurs west of 123° 30' west longitude.

The following information is derived from multi-commodity occurrence distributions of Maps B-26 through B-30:

1) Where precious metals occur with molybdenum, silver is invariably present.

2) Lead is commonly reported with silver; with one exception, silver is absent from lead deposits only in small showings or prospects which may not have assayed for silver.

3) Lead occurs most commonly with zinc east of Hope.

4) Gold occurs without silver only east of Pitt and Fire Lakes.

Commodity distribution maps each present every occurrence of a commodity according to deposit size and ranking among other metals in each deposit. Examination of these maps reveals that distribution patterns would have been considerably different for many metals had only first-reported (or first-ranked) commodities been portrayed. A first-ranked commodity map for molybdenum would imply that none is present in the Coast Plutonic Belt whereas, in fact, molybdenum occurrences are more common in intrusions of this belt than are occurrences of other metals studied. Since zinc is rarely reported as a first-ranked commodity, this relatively common metal would not have shown up on such a map. Similar variations apply to lead, silver and copper; even inclusion of second-ranked commodities will not always lead to satisfactory representation of the distribution of a metal (<u>cf</u>. lead, zinc).

SUMMARY

A statistical examination of deposit characteristics in the study area has led to the following observations:

1) Dominant metals, in order of abundance of occurrences, are copper, gold, silver, zinc, lead and molybdenum.

2) Dominant deposit types, in order of numerical abundances, are vein, porphyry and disseminated.

3) The distribution of metals among major and producing deposits generally reflects total metal abundances.

4) The distribution of deposit types among major and producing deposits does not reflect total deposit type abundances. Porphyry, disseminated and magmatic deposit types are either uncommonly present or uncommonly producers, and yet each is host to a major deposit. The most abundant deposits with the majority of producers in the area are veins, and yet only one major deposit is a vein. Volcanogenic deposits have only been recognized in the area twice, and yet one of these deposits, Britannia, is of colossal proportions relative to other occurrences in the area.

   Additional discrepancies between major deposits and other factors include the following:

   a) Seventy-four percent of all deposits in clastic rocks are veins, and yet the major deposits are disseminated (Aurum) and porphyry (Canam).

   b) Porphyries are singularly dominant in intrusive rocks, and yet the only producing porphyry (Canam) is in sedimentary rocks.

   c) Disseminated and shear deposits dominate volcanic rocks, and yet the major disseminated deposit is in sedimentary rocks (Aurum).

5) Molybdenum occurs generally in porphyry deposits in intrusive rocks.

6) Nickel occurs generally in magmatic deposits in ultramafic rocks whose distribution is centered around the Giant Mascot Ultramafite.

7) Skarn deposits generally occur in limestone.

8) Intermediate to acid intrusive rocks are poorly mineralized.

9) Pendant rocks in the Coast Plutonic Belt are well mineralized.

10) With the exception of the Cascade Belt, geologic units across the area with considerable volcanic rocks are well-mineralized by vein, shear, disseminated and massive deposits.

11) Clastic sedimentary rocks also report considerable mineralization, but only the Ladner Group reports a significant number of occurrences.

12) The most economically favorable host rock units in the area are the Gambier Group and the Ladner Group; each contain high numbers of occurrences and two major deposits.

5. CONCLUSIONS AND METALLOGENY

The tectonic model presented briefly in Chapter Two implies the presence of (at least) two episodes of subduction which resulted in formation of the Cretaceous Coast Plutonic Complex and the Tertiary Cascade Belt. Intense plutonism in Cretaceous time, collision of the Coast Plutonic arc with the Intermontane arc in mid-Cretaceous time, and considerable right-lateral movement along major faults in Tertiary time have significantly disguised original relationships in the area. In this context, it becomes difficult not only to unravel the tectonic history, but to relate the metallogenic history to the tectonic framework.

Examination of major deposits, districts of significant concentrations of deposits, and deposits with production records has served to describe the dominant areas of interest and relate them to the tectonic evolution of the area. The results of the descriptive work in Chapter Three are illustrated on the time-space plot of Figure 2-2. The distribution of mineralization here implies that the great majority of deposits were formed (a) throughout the Coast Plutonic Belt and (b) spatially related to the Hozameen Fault during Cretaceous collision and plutonism. This epoch of mineralization includes the five major deposits found in the study area. Less abundant mineralization occurred in Oligocene-Miocene time.

As attractive as this model of two metallogenic epochs may be, it is in part a built-in result of the manner in which this study was undertaken. Determination of the age of mineralization of many camps is little more than supposition; if mineralization is assumed to be epigenetic, it is also assumed to be the product of observed deformation or plutonism. These assumptions are believed by the author to be reasonable, although supportive evidence commonly is lacking.

Major mineralization characterizing the Cretaceous episode includes:

1) volcanogenic copper-zinc sulfide deposition (Britannia) in volcano-sedimentary rocks of the Coast Plutonic arc,

2) formation of a gold-silver-lead-zinc vein (?; Northair) in volcanic pendant rocks of the Coast Plutonic Belt,

3) magmatic nickel-copper sulfide formation (Giant Mascot) in the axial metamorphic core of the Spuzzum Plutonic Belt,

4) introduction of gold in veins and disseminations (Ladner Gold) in rocks adjacent to the deep-seated Hozameen Fault and serpentine belt, and

5) formation of a copper-rich breccia pipe (Canam) in sedimentary rocks adjacent to the Hozameen Fault.

Formation of copper-zinc sulfide deposits (Harrison Lake District) prior to Cretaceous time occurred during acidic volcanism of the Middle Jurassic Harrison Lake Formation. Mineralization might have occurred during deposition of the Hozameen Group in Upper Paleozoic time, but too little is known about these deposits to put much emphasis on this suggestion.

The application of statistical tabulations to information accumulated on metal occurrences in the study area has revealed some interesting relationships. Although major deposits reflect the general abundance of metals in the area, they do not correspond to the most common deposit types. This is unfortunately a poor reflection of the classification scheme used in this study, as all of the major deposits (except Canam) are located in areas where they should be expected to occur on the basis of geology and surrounding metal occurrences. For this reason, a detailed knowledge of the geology and characteristics of individual occurrences has proved invaluable.

The most notable results of the statistical study pertain to the control of host rock type over mineralization. Intrusive rocks are singularly characterized by molybdenum and nickel sulfide occurrences in intermediate to acid varieties and ultramafic rocks, respectively. The source of nickel corresponds to its inherently nickel-rich host rock, and since molybdenum occurrences are restricted to intermediate to acid intrusive rocks, the source of this metal also is assumed to be its host intrusion.

Clastic sedimentary rocks primarily contain vein deposits with predominant precious metal (mainly gold) content. However, this abundance of deposits is restricted to the Ladner Group, specifically along the serpentine belt of the Hozameen Fault. Gold deposits, therefore, are controlled by tectonic environment, not rock type. Other clastic sedimentary units in the area (especially the slaty, turbiditic Cultus Formation) are poorly mineralized. It is on this basis that a mid-Cretaceous epigenetic origin and not a Middle Jurassic syngenetic origin is favored for the disseminated gold deposit in the Ladner Gold Belt. A source for the gold in this area can probably be related to deep-seated sources (sub-crustal?) which were tapped by the Hozameen Fault. The fact that gold occurrences are most prominent along the fault where ultramafic rocks occur suggests a genetic relationship.

Volcanic rocks are most commonly mineralized by shear, vein and disseminated deposits, which may also describe portions of volcanogenic deposits. Since (a) Britannia is surrounded by shears which look similar to sulfide occurrences in the Britannia orebodies, and (b) Seneca is surrounded by disseminated occurrences which are similar to portions of the Seneca deposit, all such occurrences are likely "volcanogenic-type" deposits.

With the exception of molybdenum and nickel, the predominant metals in the area are copper, silver, gold, zinc and lead, in decreasing order of abundance. Since this assemblage is characteristic of volcanic rocks, it is suggested that in the study area these metals, originally accumulated in volcanic rocks, were subsequently remobilized into epigenetic deposits.

Integration of this information with the tectonic and metallogenic history of the area indicates that arc volcanism of the Coast Plutonic Belt is primarily responsible for the original accumulations of metals. Cretaceous collision with the Cascade and Intermontane Belts remobilized these original accumulations; Tertiary Cascade plutonism (and volcanism?) was also responsible for some remobilization. During the collision episode, access to sub-crustal sources through ultramafic intrusion and deep-seated faulting introduced nickel and gold accumulations along the collision axis. Formation of molybdenum deposits, although definitely correlated with plutonism, is not restricted to any particular episode.

Computer inventory files are potential assets to regional studies such as this one, but its applications are limited. As a data storage bank for information necessary to acquaint one with mineral deposits in a specified area, its potential is indisputed, however, it was necessary in this study to do most tabulation manually. Statistical analyses of such data require areas which are tailor-made to the problem under examination. For example, a detailed study of a small area with a high density of occurrences is practical if the geology is relatively uncomplicated and applications are on a small scale. But if large-scale problems are to be tackled, a much larger area should be examined to eliminate small-scale variations in the large-scale picture. The conclusions reached in this study are based on a very small population relative to the large-scale features discussed, and should be regarded in this light.

REFERENCES CITED

Aho, Aaro E. (1956): Geology and genesis of ultrabasic nickel-copper-pyrrhotite deposits at the Pacific Nickel Property, southwestern British Columbia, Economic Geology, Vol. 51, p. 444-81.

Anderson, Phillip (1971): Geology, petrology, origin and metamorphic history of the Eagle "Granodiorite" and Nicola Group at Whipsaw Creek, Princeton area, southern British Columbia, umpublished B.Sc. thesis, University of British Columbia, 201 p.

Baadsgaard, H., Folinsbee, R. E., and Lipson, J. (1961): Potassium-argon dates of biotites from Cordilleran granites, Geol. Soc. Am. Bull., Vol. 72, p. 689-702.

Beaty, Ross J. (1974): Low grade metamorphism of Permian to Early Cretaceous volcanic and volcaniclastic rocks near Chilliwack, British Columbia, unpublished B.Sc. thesis, University of British Columbia, 51 p.

Bostock, H. H. (1963): Geology of Squamish (Vancouver, West Half), British Columbia, Geol. Surv. Can. Map 42-1963.

Brookfield, M. E. (1973): Lower Oxfordian (Upper Jurassic) sediments at Harrison Lake, British Columbia, and the age of the "Agassiz Orogeny," Can. Jour. Earth Sc., Vol. 10, p. 1688-92.

Brown, E. H. (1977): The crossite content of Ca-amphibole as a guide to pressure of metamorphism, Jour. Petrology, Vol. 18, p. 53-72.

Cairnes, C. E. (1924): Coquihalla area, British Columbia, Geol. Surv. Can. Memoir 139, 187 p.

Cairnes, C. E. (1929): The serpentine belt of Coquihalla region, Yale District, British Columbia, Geol. Surv. Can. Summary Report, p. 144-97.

Cameron, B. E. B., and Monger, J. W. H. (1971): Middle Triassic conodonts from the Fergusson Group, northwestern Pemberton map-area, Geol. Surv. Can. Rept. Act., Paper 71-1, pt. B., p. 94.

Caron, M. E. (1974): Geology and geochronology of the Strachan Creek area, Howe Sound, southwestern British Columbia, unpublished B.Sc. thesis, Univeristy of British Columbia, 33 p.

Christopher, P. A., and Robinson, J. W. (1974): Pride of Emory Mine, B. C. Dept. of Mines and Pet. Res., G. E. M., p. 105-13.

Clarke, W. E. (1969): Geology and ore controls (Giant Mascot Mines Limited), Western Miner, Vol. 42, June, p. 41-6.

Coates, J. A. (1974): Geology of the Manning Park area, British Columbia, Geol. Surv. Can. Bull. 238, 177 p.

Cockfield, W. E. (1948): Geology and mineral deposits of Nicola map-area, British Columbia, Geol. Surv. Can. Memoir 249, 164 p.

Cockfield, W. E., and Walker, J. F. (1933): The nickel-bearing rocks near Choate, British Columbia, Geol. Surv. Can. Summary Report, p. 62A-68A.

Crickmay, C. H., Horwood, H. C., and Snow, W. E. (1944): Hope; Yale and New Westminster Districts, British Columbia, Geol. Surv. Can. Map 737A

Danner, W. R. (1976): Limestone resources of Southwestern British Columbia, Montana Bureau of Mines and Geol. Spec. Publ. 74

Dickson, M. P., and McLeod, D. A. (1975): Northair Mines: Grass roots to senior financing, Can. Mining Jour., Vol. 96, April, p. 79-82.

Duffell, S., and McTaggart, K. C. (1952): Ashcroft map-area, British Columbia, Geol. Surv. Can. Memoir 262, 122 p.

Green, N. L. (1977): Multistage andesite genesis in the Garibaldi Lake area, southwestern British Columbia, unpublished Ph.D. thesis, University of British Columbia, 246 p.

Griffiths, J. R. (1977): Geology and metallogeny of the Lachlan Orogen, Australia: A time-space analysis and preliminary tectonic synthesis, CSIRO Minerals Research Laboratories, Div. of Mineral Physics, Investigation Rept. 123, 42 p.

Hodgson, C. J., and Lydon, J. W. (1977): Geological setting of volcanogenic massive sulfide deposits and active hydrothermal systems: Some implications for exploration, CIM Bull., Vol. 70, October, p. 95-106.

Hollister, L. S. (1969a): Metastable paragenetic sequence of andalusite, kyanite and sillimanite, Kwoiek area, British Columbia, Am. Jour. Sc., Vol. 267, p. 352-70.

________________ (1969b): Contact metamorphism in the Kwoiek area of British Columbia: An end member of the metamorphic process, Geol. Soc. Am. Bull. 80, p. 2465-94.

Horwood, H. C. (1936): Geology and mineral deposits at the mine of B. C. Nickel Mines Limited, Yale District, B. C., Geol. Surv. Can. Memoir 190, p. 1-15.

Irvine, W. T. (1946): Geology and development of the No. 8 orebodies, Britannia Mines, B. C., CIM Bull. 407, p. 191-214.

James, H. T. (1929): Britannia Beach map-area, British Columbia, Geol. Surv. Can. Memoir 158, 139 p.

Kayira, G. (1975): A mineralographic and petrographic study of the gold deposit of the Upper Idaho Zone, Hope, British Columbia, unpublished B.Sc. thesis, University of British Columbia, 74 p.

Leech, G. B., Lowdon, J. A., Stockwell, C. H., and Wanless, R. K. (1963): Age determinations and geological studies, Geol. Surv. Can. Paper 63-17, p. 38-9.

Little, L. (1974): A mineralography study of Brandywine Property lead-zinc-gold-silver deposit, Brandywine map area, southwestern British Columbia, unpublished Geology 409 report, University of British Columbia, 57 p.

Lowes, B. E. (1972): Metamorphic petrology and structural geology of the area east of Harrison Lake, British Columbia, unpublished Ph.D. thesis, University of Washington, 161 p.

Manifold, A. H. (1976): Some aspects of Northair Mines' Brandywine property, preprint of paper presented at the Annual Meeting of CIM District 6, October 13-15, 15 p.

Mathews, W. H. (1958): Geology of the Mount Garibaldi map-area, southwestern British Columbia, Canada, Geol. Soc. Am. Bull., Vol. 69, p. 161-78.

Mattinson, J. M. (1972): Ages of Zircons from the Northern Cascade Mountains, Washington, Geol. Soc. Am. Bull., Vol. 83, p. 3769-84.

McKillop, G. R. (1973): Geology of southwestern Gambier Island, Howe Sound, British Columbia, unpublished B.Sc. thesis, University of British Columbia, 25 p.

McLeod, J. A. (1975): The Giant Mascot Ultramafite and its related ores, unpublished M.Sc. thesis, University of British Columbia, 123 p.

McLeod, J. A., Vining, M., and McTaggart, K. C. (1976): Note on the age of the Giant Mascot ultramafic body, near Hope, British Columbia, Can. Jour. Earth Sc., Vol. 13, p. 1152-4.

McTaggart, K. C. (1971): On the origin of ultramafic rocks, Geol. Soc. Am. Bull., Vol. 82, p. 23-42.

McTaggart, K. C., and Thompson, R. M. (1967): Geology of part of the Northern Cascades in southern British Columbia, Can. Jour. Earth Sc., Vol. 4, p. 1199-228.

Miller, J. H. L., Sinclair, A. J., Manifold, A. H., and Wetherell, D. (1978): Mineral deposits in the Callaghan Creek area, southwestern British Columbia, preprint of paper presented at the 80th AGM of the CIM, April 23-27, Vancouver, B. C., 7 p.

Misch, P. (1966): Tectonic evolution of the Northern Cascades of Washington State, in Tectonic History and Mineral Deposits of the Western Cordillera, CIM Spec. Vol. No. 8, p. 101-48.

__________ (1977): Bedrock geology of the North Cascades (Field Trip No. 1), Geological Excursions in the Pacific Northwest, GSA Annual Meeting, Seattle, WA, p. 1-24.

Monger, J. W. H. (1970): Hope map area, west half, British Columbia, Geol. Surv. Can. Paper 69-47, 75 p.

______________ (1977): Upper Paleozoic rocks of the Western Canadian Cordillera and their bearing on Cordilleran evolution, Can. Jour. Earth Sc., Vol. 14, p. 1832-59.

Monger, J. W. H., Souther, J. G., and Gabrielse, H. (1972): Evolution of the Canadian Cordillera: A plate tectonic model, Am. Jour. Sc., Vol. 272, p. 577-602.

Montgomery, J. H., Sinclair, A. J., Symonds, D. F., and Giroux, G. H. (1977): Geostatistical study of the Ladner Creek gold deposit of Carolin Mines Ltd., Western Miner, Vol. 50, March, p. 11-22.

Naldrett, A. J. (1973): Nickel sulfide deposits - their classification and genesis, with special emphasis on deposits of volcanic association, Trans. CIMM, Vol. 76, p. 183-201.

Naldrett, A. J., and Cabri, L. J. (1976): Ultramafic and related mafic rocks: their classification and genesis with special reference to the concentration of nickel sulfides and platinum-group elements, Ec. Geol., Vol. 71, p. 1131-58.

Orr, J. F. W., and Sinclair, A. J. (1971): A computer-processible file for mineral deposits in the Slocan and Slocan City areas of British Columbia, Western Miner, Vol. 44, April, p. 22-34.

Payne, J. G., Bratt, J. A., and Stone, B. G. (1978): Deformed Mesozoic volcanogenic copper-zinc sulfide deposits in the Britannia District, British Columbia, Ec. Geol., in press.

Pigage, L. C. (1976): Metamorphism of the Settler Schist, southwest of Yale, British Columbia, Can. Jour. Earth Sc., Vol. 13, p. 405-21.

Pilcher, S. H., and McDougall, J. J. (1976): Characteristics of some Canadian Cordilleran Porphyry Prospects, _in_ Porphyry Deposits of the Canadian Cordillera, CIM Spec. Vol. No. 15, p. 79-82.

Read, P. B. (1960): The geology of the Fraser Valley between Hope and Emory Creek, British Columbia, unpublished M.Sc. thesis, University of British Columbia, 154 p.

Reamsbottom, S. B. (1974): Geology and metamorphism of the Mount Breakenridge area, Harrison Lake, British Columbia, unpublished Ph.D. thesis, University of British Columbia, 155 p.

Rice, H. M. A. (1960): Geology and mineral deposits of the Princeton map-area, British Columbia, Geol. Surv. Can. Memoir 243, 136 p.

Richards, T. A., and McTaggart, K. C. (1976): Granitic rocks of the southern Coast Plutonic Complex and Northern Cascades of British Columbia, Geol. Soc. Am. Bull., Vol. 87, p. 935-53.

Richards, T. A., and White, Wm. H. (1970): K-Ar ages of plutonic rocks between Hope, British Columbia, and the 49th parallel, Can. Jour. Earth Sc., Vol. 7, p. 1203-7.

Roddick, J. A. (1965): Vancouver North, Coquitlam, and Pitt Lake map-areas, British Columbia, with special emphasis on the evolution of the plutonic rocks, Geol. Surv. Can. Memoir 335, 276 p.

Roddick, J. A., and Hutchison, W. W. (1969): Northwestern part of Hope map area, British Columbia (92H/West Half), Geol. Surv. Can. Paper 69-1, pt. A., p. 29-38.

____________________ (1973): Pemberton (East Half) map-area, British Columbia, Geol. Surv. Can. Paper 73-17, 21 p.

Roddick, J. A., and Okulitch, A. V. (1973): Fraser River, Geol. Surv. Can. Open File Map No. 165, July.

Roddick, J. A., Mathews, W. H., and Woodsworth, G. J. (1977): Southern end of the Coast Plutonic Complex, Geol. Assoc. Can. Annual Meeting, Vancouver, British Columbia, Field Trip No. 9, 33 p.

Schofield, S. J. (1918): Britannia map area, British Columbia, Geol. Surv. Can. Summary Report, p. 56B-59B.

__________ (1922): Ore deposits of British Columbia, in Geology and ore deposits of Salmon River District, British Columbia, Geol. Surv. Can. Memoir 132, p. 63-73.

__________ (1926): The Britannia Mines, British Columbia, Ec. Geol., Vol. 21, p. 271-84.

Sinclair, A. J., Wynne-Edwards, H. R., and Sutherland Brown, A. (1978): An analysis of distribution of mineral occurrences in British Columbia, B. C. Dept. Mines and Pet. Res. Bull., in press.

Staatz, M. H., Tabor, R. W., Weis, P. L., Robertson, J. F., Van Noy, R. M., and Pattee, E. C. (1972): Geology and mineral resources of the northern part of the North Cascades National Park, Washington, U. S. Geol. Surv. Bull. 1359, 132 p.

Staatz, M. H., Weis, P. L., Tabor, R. W., Robertson, J. F., Van Noy, R. M., Pattee, E. C., and Holt, D. C. (1971): Mineral resources of the Pasayten Wilderness Area, Washington, U. S. Geol. Surv. Bull. 1325, 255 p.

Sutherland Brown, A., and Cathro, R. J. (1976): A perspective of porphyry deposits, in Porphyry deposits of the Canadian Cordillera, CIMM Spec. Vol. 15, p. 7-16.

Sutherland Brown, A., and Robinson, J. W. (1970): Britannia Mine, B. C. Dept. of Mines and Pet. Res., G. E. M., p. 233-45.

Sutherland Brown, A., Cathro, R. J., Pantaleyev, A., and Ney, C. S. (1971): Metallogeny of the Canadian Cordillera, CIM Bull., Vol. 64, No. 709, p. 37-61.

Tabor, R. W., Engels, J. C., and Staatz, M. H. (1968): Quartz diorite-quartz monzonite and granitic plutons of the Pasayten River area, Washington - petrology, age and emplacement, U. S. Geol. Surv. Prof. Paper 600-C, p. C45-52.

Turekian, K. K., and Wedepohl, K. H. (1961): Distribution of the elements in some major units of the earth's crust, Geol. Soc. Am. Bull., Vol. 72, p. 175-92.

Van Eysinga, F. W. B. (1975): Geological Time Table, 3rd edition.

Vining, M. R. (1977): The Spuzzum pluton northwest of Hope, British Columbia, unpublished M.Sc. thesis, University of British Columbia, 147 p.

Wanless, R. K., Stevens, R. D., Lachance, G. R., and Delabio, R. N. (1973): Age determinations and geological studies, K-Ar isotopic ages, Report No. 11, Geol. Surv. Can. Paper 73-2, p. 9-13.

______________ (1977): Age determinations and geological studies, K-Ar isotopic ages, Report No. 13, Geol. Surv. Can. Paper 77-2, p. 11-14.

Wanless, R. K., Stevens, R. D., Lachance, G. R., and Edmonds, C. M. (1967): Age determinations and geological studies, K-Ar isotopic ages, Report No. 7, Geol. Surv. Can. Paper 66-17, p. 11-14.

White, Wm. H. (1968): Granitic rocks of southwestern British Columbia, in Guidebook for Geological Field Trips in Southwestern British Columbia, U.B.C. Geology Dept. Rept. No. 6, W. H. Mathews, ed., April, p. 13-17.

Woodsworth, G. J. (1977): Pemberton (92J) map-area, Geol. Surv. Can. Open File Map No. 482.

Woodsworth, G. J., Pearson, D. E., and Sinclair, A. J. (1977): Metal distribution patterns across the eastern flank of the Coast Plutonic Complex, south-central British Columbia, Ec. Geol., Vol. 72, p. 170-83.

APPENDIX A

STATISTICAL DATA BASE

TABLE A-1. DISTRIBUTION OF COMMODITY OCCURRENCES INTO DEPOSIT TYPES[1]

	iron	cobalt	nickel	copper	zinc	arsenic	molybdenum	silver	cadmium	antimony	tungsten	gold	lead	bismuth	uranium
veins		1		45 (13)	20 (9)	2 (1)	1	44 (16)		2	2 (1)	64 (18)	26 (9)		
shears	1 (1)	1	1	17 (2)	12 (1)		1	13 (2)			1 (1)	10 (2)	7 (1)		
disseminated	1		1	31 (1)	20 (1)	1	1	14 (1)		5 (1)	1 (1)	10	9 (1)	1	
massive	1			4	2			1				2			
magmatic	1 (1)		13 (1)	13 (1)	1			1				1			
skarns	10 (2)		2	20 (4)	11 (1)		5 (2)	15 (3)			1	10 (1)	5		
porphyries	3 (1)			37 (2)	5		33 (2)	14 (2)			1	7 (1)	1 (1)	1	1 (1)
volcanogenic	1 (1)			2 (2)	2 (2)			2 (2)				2 (2)	2 (2)		
unknown	2		2	15	9		1	9				8	5		

[1]The lower number in parentheses is the number of commodity occurrences from deposits with production records; this number is included in the total count above it.

TABLE A-2. NUMBER OF COMMODITY OCCURRENCES AND DEPOSIT TYPES IN EACH TECTONIC BELT OR BELT SUBDIVISION IN THE STUDY AREA[1]

	iron	cobalt	nickel	copper	zinc	arsenic	molybdenum	silver	cadmium	antimony	tungsten	gold	lead	bismuth	uranium	magmatic	porphyry	skarn	volcanogenic	vein	shear	disseminated	massive	Total
Coast Plutonic Belt Intrusions 10,187 Km^2	2		1	32 (3)	5 (1)		19 (1)	9 (3)				7 (2)	1			1	21 (1)			8 (1)	1	4		35 (2)
Coast Plutonic Belt Pendants 2,652 Km^2	10 (3)			59 (9)	32 (7)		4 (1)	30 (9)		1 (1)	3 (3)	25 (9)	15 (6)	1			7	9 (2)	2 (2)	13 (5)	14 (2)	19 (1)	1	65 (12)
Spuzzum Plutonic Belt Intrusions 3,097 Km^2		1	10 (1)	11 (1)	1		2	1		1	1	3	1	1		8 (1)	2			2	1	1		14 (1)
Spuzzum Plutonic Belt Pendants 1,145 Km^2		1	1	4 (1)		1 (1)		4 (1)				3 (1)						1		4 (1)		1		6 (1)
Cascade Belt 1,619 Km^2	3 (1)		2	15 (3)	6		6 (1)	14 (3)			1	9	7 (1)			1	4	7 (2)		7 (1)	1	3		23 (3)
Hozameen Basin 1,111 Km^2	3		3	16 (1)	10 (1)	1	3	15 (1)		3	1	17 (1)	8 (1)			2	1	4		5 (1)		7	4	23 (1)
Ladner Trough 1,875 Km^2	1 (1)		1	21 (7)	17 (5)	1	2 (1)	22 (9)		2		37 (11)	15 (6)		1 (1)	1	1 (1)			34 (10)	7	2		45 (11)
Eagle Plutonic Belt 1,787 Km^2	1		1	18	6		5	9	1			10	6			1	5	2		7		2		17
Total 23,473 Km^2	20 (5)	2	19 (1)	176 (25)	77 (14)	3 (1)	41 (4)	104 (26)	1	7 (1)	6 (3)	111 (24)	53 (14)	2	1 (1)	14 (1)	41 (2)	23 (4)	2 (2)	80 (19)	24 (2)	39 (1)	5	228 (31)

[1]The lower number in parentheses is the number of deposits with production records; this number is included in the total count above it.
Areal calculations are included below each division name.

TABLE A-3. DENSITIES (NUMBER OF DEPOSITS/100 MI^2) OF COMMODITY OCCURRENCES AND DEPOSIT TYPES IN EACH TECTONIC BELT OR BELT SUBDIVISION IN THE STUDY AREA[1]

	iron	cobalt	nickel	copper	zinc	arsenic	molybdenum	silver	cadmium	antimony	tungsten	gold	lead	bismuth	uranium	magmatic	porphyry	skarn	volcanogenic	vein	shear	disseminated	massive	Total
Coast Plutonic Belt Intrusions	.05		.03	.81 (.08)	.13 (.03)		.48 (.03)	.23 (.08)				.18 (.05)	.03			.03	.53 (.03)			.21 (.03)	.03	.10		.89 (.05)
Coast Plutonic Belt Pendants	.98 (.29)			5.76 (.88)	3.13 (.68)		.39 (.10)	2.93 (.88)		.10 (.10)	.29 (.29)	2.44 (.88)	1.46 (.59)	.10			.68	.88 (.20)	.20	1.27 (.49)	1.37 (.20)	1.86 (.10)	.10	6.35 (1.17)
Spuzzum Plutonic Belt Intrusions		.08	.84 (.08)	.92 (.08)	.08		.17	.08		.08	.08	.25	.08	.08		.67 (.08)	.17			.17	.08	.08		1.17 (.08)
Spuzzum Plutonic Belt Pendants		.23	.23	.90 (.23)		.23		.90 (.23)				.68 (.23)						.23		.90 (.23)		.23		1.36 (.23)
Cascade Belt	.48 (.16)		.32	2.40 (.48)	.96		.96 (.16)	2.24 (.48)			.16	1.44	1.12 (.16)			.16	.64	1.12 (.32)		1.12 (.16)	.16	.48		3.68 (.48)
Hozameen Basin	.70		.70	3.73 (.23)	2.33 (.23)	.23	.70	3.50 (.23)		.70	.23	3.96 (.23)	1.86 (.23)			.47	.23	.93		1.17 (.23)		1.63	.93	5.36 (.23)
Ladner Trough	.14 (.14)		.14	2.90 (.97)	2.35 (.69)	.14	.28 (.14)	3.04 (1.24)		.28		5.11 (1.52)	2.07 (.83)		.14 (.14)	.14	.14 (.14)			4.70 (1.38)	.97	.28		6.23 (1.52)
Eagle Plutonic Belt	.14		.14	2.61	.87		.72	1.30	.14			1.45	.87			.14	.72	.29		1.01		.29		2.46
Total	.22 (.06)	.02	.21 (.01)	1.94 (.28)	.85 (.15)	.03 (.01)	.45 (.04)	1.15 (.29)	.01	.08 (.01)	.07 (.03)	1.22 (.26)	.58 (.15)	.02	.01 (.01)	.15 (.01)	.45 (.02)	.25 (.04)	.02 (.02)	.88 (.21)	.26 (.02)	.43 (.01)	.06	2.52 (.34)

[1]The lower number in parentheses is the number of deposits with production records; this number is included in the total count above it.

TABLE A-4. RELATIVE DENSITIES OF COMMODITY OCCURRENCES AND DEPOSIT TYPES IN EACH TECTONIC BELT OR BELT SUBDIVISION IN THE STUDY AREA[1]

	iron	cobalt	nickel	copper	zinc	arsenic	molybdenum	silver	cadmium	antimony	tungsten	gold	lead	bismuth	uranium	magmatic	porphyry	skarn	volcanogenic	vein	shear	disseminated	massive	Total
Coast Plutonic Belt Intrusions	.23		.14	.42 (.04)	.15 (.03)		1.07 (.07)	.20 (.07)				.15 (.04)	.05			.20	1.18 (.07)			.24 (.03)	.12	.23		.35 (.02)
Coast Plutonic Belt Pendants	4.45 (1.32)			2.97 (.45)	3.68 (.80)		.87 (.22)	2.55 (.77)		1.25 (1.25)	4.14 (4.14)	2.00 (.72)	2.52 (1.02)	5.00			1.51	3.52 (.80)	10.00 (10.00)	1.44 (.56)	5.27 (.77)	4.33 (.23)	1.67	2.52 (.46)
Spuzzum Plutonic Belt Intrusions		.07	4.00 (.38)	.47 (.04)	.09		.38	.07		1.00	1.14	.20	.14	4.00		4.47 (.53)	.38			.19	.31	.19		.46 (.03)
Spuzzum Plutonic Belt Pendants		1.10	1.10	.46 (.12)		7.67 (7.67)		.78 (.20)				.56 (.19)						.92		1.02 (.26)		.53		.54 (.09)
Cascade Belt	2.18 (.73)		1.52	1.24 (.25)	1.13		2.13 (.35)	1.95 (.42)			2.29	1.18	1.93 (.28)			1.07	1.42	4.48 (1.28)		1.27 (.18)	.62	1.12		1.46 (.19)
Hozameen Basin	3.18		3.33	1.92 (.12)	2.74 .27	7.67	1.56	3.04 (.20)		8.75	3.29	3.25 (.19)	3.21 (.40)			3.13	.51	3.72		1.33 (.26)		3.79	15.50	2.13 (.09)
Ladner Trough	.64 (.64)		.67	1.49 (.50)	2.76 (.81)	4.67	.62 (.31)	2.64 (1.08)		3.50		4.19 (1.25)	3.57 (1.43)		14.00 (14.00)	.93	.31 (.31)			5.34 (1.57)	3.73	.65		2.47 (.60)
Eagle Plutonic Belt	.64		.67	1.35	1.02		1.60	1.13	14.00			1.19	1.50			.93	1.60	1.16		1.15		.67		.98
Total	1.00 (.27)	1.00	1.00 (.05)	1.00 (.14)	1.00 (.18)	1.00 (.33)	1.00 (.09)	1.00 (.25)	1.00	1.00 (.13)	1.00 (.50)	1.00 (.21)	1.00 (.26)	1.00	1.00 (1.00)	1.00 (.07)	1.00 (.04)	1.00 (.16)	1.00 (1.00)	1.00 (.24)	1.00 (.08)	1.00 (.02)	1.00	1.00 (.13)

[1]The lower number in parentheses is the number of deposits with production records; this number is included in the total count above it.

	iron	cobalt	nickel	copper	zinc	arsenic	molybdenum	silver	cadmium	antimony	tungsten	gold	lead	bismuth	uranium	magmatic	porphyry	skarn	volcanogenic	vein	shear	disseminated	massive	Total
Coast Plutonic Complex	2		1	34 (4)	7 (2)		19 (1)	12 (4)		1	2 (2)	11 (3)	4 (1)			1	21 (1)			11 (2)	3 (1)	5		41 (4)
Chilliwack and Mt. Barr Batholiths	1	1		5	1		4	3				3	1				4			3				7
Needle Peak Pluton							1													1				1
Invermay Stock				2 (1)	2 (1)			2 (1)				2 (1)	1 (1)							2 (1)				2 (1)
Scuzzy/Spuzzum Plutons				3 (1)	1	1 (1)	2	1 (1)			1	1 (1)		1			2			1 (1)				3 (1)
Eagle Complex				8	3		4	3	1			3	3				4	1		1		2		8
Giant Mascot Ultramafite			1 (1)	1 (1)												1 (1)								1 (1)
Agassiz Prairie Formation				1				1														1		1
Bowen Island Group	1 (1)			2 (1)				1 (1)				1 (1)									2 (1)			2 (1)
Cheakamus Formation				1				1				1								1				1
Chilliwack Group	1 (1)			8 (2)	2		2 (1)	6 (2)			1	3	1					5 (2)		3		1		9 (2)
Chuckanut Formation				1 (1)				1 (1)					1 (1)							1 (1)				1 (1)
Cultus Formation								1				1										1		1
Custer Gneiss			1	1	2			2					2					3						3
Echo Island Formation				1	1																	1		1
Fire Lake Group				4 (1)	1 (1)			1 (1)				5 (2)	1 (1)							6 (2)				6 (2)
Gambier Group	4 (1)			21 (2)	13 (2)		1	10 (2)				7 (2)	4 (1)				2	5 (1)	1 (1)		7	5	1	21 (2)
Gambier ? Group	2 (1)			9 (4)	6 (3)		1 (1)	5 (3)		1 (1)	2 (2)	4 (3)	5 (3)				2	2 (1)		2 (1)	1 (1)	3 (1)		10 (4)
Harrison Lake Formation	1			12 (1)	9 (1)		1	5 (2)				4 (2)	3 (1)	1			2		1 (1)	2 (1)	1	8		14 (2)
Hozameen Group	2		2	16 (3)	10 (1)	1	2	14 (3)		3	1	18 (3)	7 (1)			1		4		9 (3)	1	6	3	24 (3)
Ladner Group	1 (1)			12 (5)	10 (3)	1	1 (1)	16 (7)		2		21 (8)	11 (4)		1 (1)		1 (1)			21 (7)	3	2		27 (8)
Nicola Group				6	3			5	1			8	4							8				8
Pasayten Group				2 (1)	2 (1)			1 (1)				1 (1)	1 (1)							1 (1)	1			2 (1)
Skagit Formation				1	1			1				1	1								1			1
Twin Islands Group												1								1				1

[1]The lower number in parentheses is the number of deposits with production records; this number is included in the total count above it.

TABLE A-6. NUMBER OF COMMODITY OCCURRENCES AND DEPOSIT TYPES IN HOST ROCK TYPES IN THE STUDY AREA[1]

	iron	cobalt	nickel	copper	zinc	arsenic	molybdenum	silver	cadmium	antimony	tungsten	gold	lead	bismuth	uranium	magmatic	porphyry	skarn	volcanogenic	vein	shear	disseminated	massive
basic volcanic rocks; greenstone	6 (3)			38 (8)	24 (4)		3 (1)	20 (7)		4 (1)	2 (2)	21 (7)	14 (4)	1			1	2 (1)	1 (1)	15 (4)	9 (2)	15 (1)	3
acid volcanic rocks	3 (1)			12 (2)	10 (2)		2	6 (2)	1			4 (2)	5 (2)	1			2	1	2 (2)	2		5	
pyroclastic volcanic rocks	2 (1)			9 (1)	13 (4)	2		8 (5)		3		8 (5)	6 (4)	1						6 (4)	1 (1)	7	
unclassified volcanic rocks				13	4		1	6				7	4				3			6	5	2	
dikes				9 (2)	4 (1)		2	8 (2)			2 (2)	7 (2)	2 (1)				4	1		4 (1)	1 (1)	3	
intermediate to acid intrusive rocks	2	1		46 (4)	14 (2)	1 (1)	28 (1)	22 (4)	1	1	2	19 (3)	11 (1)	1			28 (1)	2		16 (3)	2	9	
ultramafic rocks	1	1	15 (1)	15 (2)	1			4 (1)				6 (1)				14 (1)				2 (1)	3	1	
clastic sedimentary rocks	2 (1)			21 (7)	10 (4)	1	2 (1)	24 (9)		2		29 (9)	10 (6)		1 (1)		1 (1)	2		28 (9)	1	6	
limestone	8 (2)		2	22 (4)	11 (1)	1	4 (1)	19 (4)	1		1	14 (2)	6				1	19 (3)		3	1 (1)	1	
unclassified sedimentary rocks	3 (1)			10 (2)	8 (1)		2	6 (2)		2		6 (2)	4 (1)				1	2		1 (1)	3 (1)	5	
schist				6	2		1	2				1					2			1	1	3	
unknown	2		2	26 (1)	14 (1)		5	15 (2)				22 (3)	9 (1)				5			12 (3)	2	1	2

[1]The lower number in parentheses is the number of deposits with production records; this number is included in the total count above it.

APPENDIX B

DEPOSIT DISTRIBUTION MAPS

TABLE B-1. SYMBOL DEFINITIONS FOR DEPOSIT DISTRIBUTION MAPS

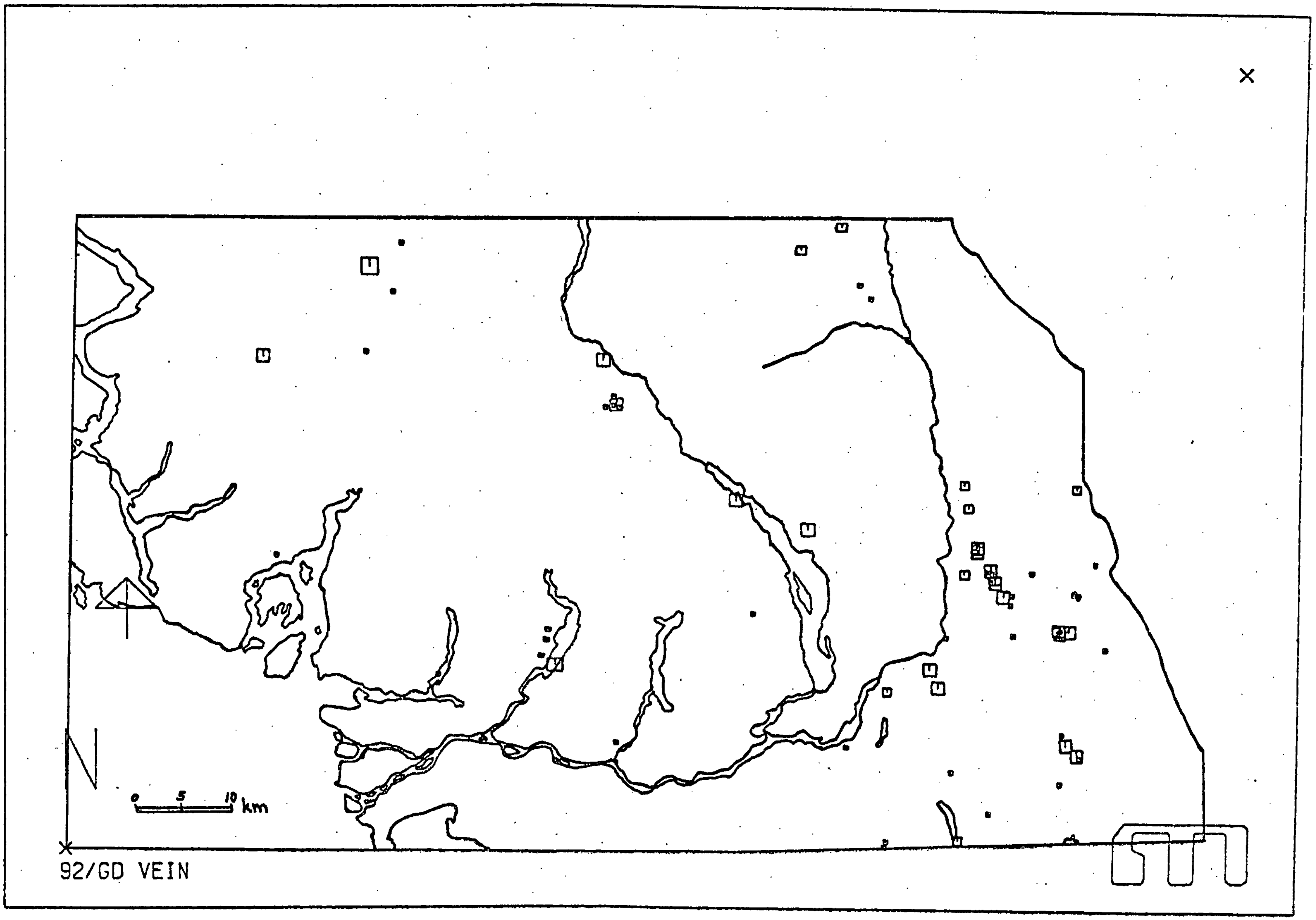
Unless specified on the map, symbols used to designate deposit locations are defined by deposit type as follows:

Vein	
Skarn	
Disseminated	
Shear	
Magmatic	
Volcanogenic	
Porphyry	
Massive	
Unknown	×

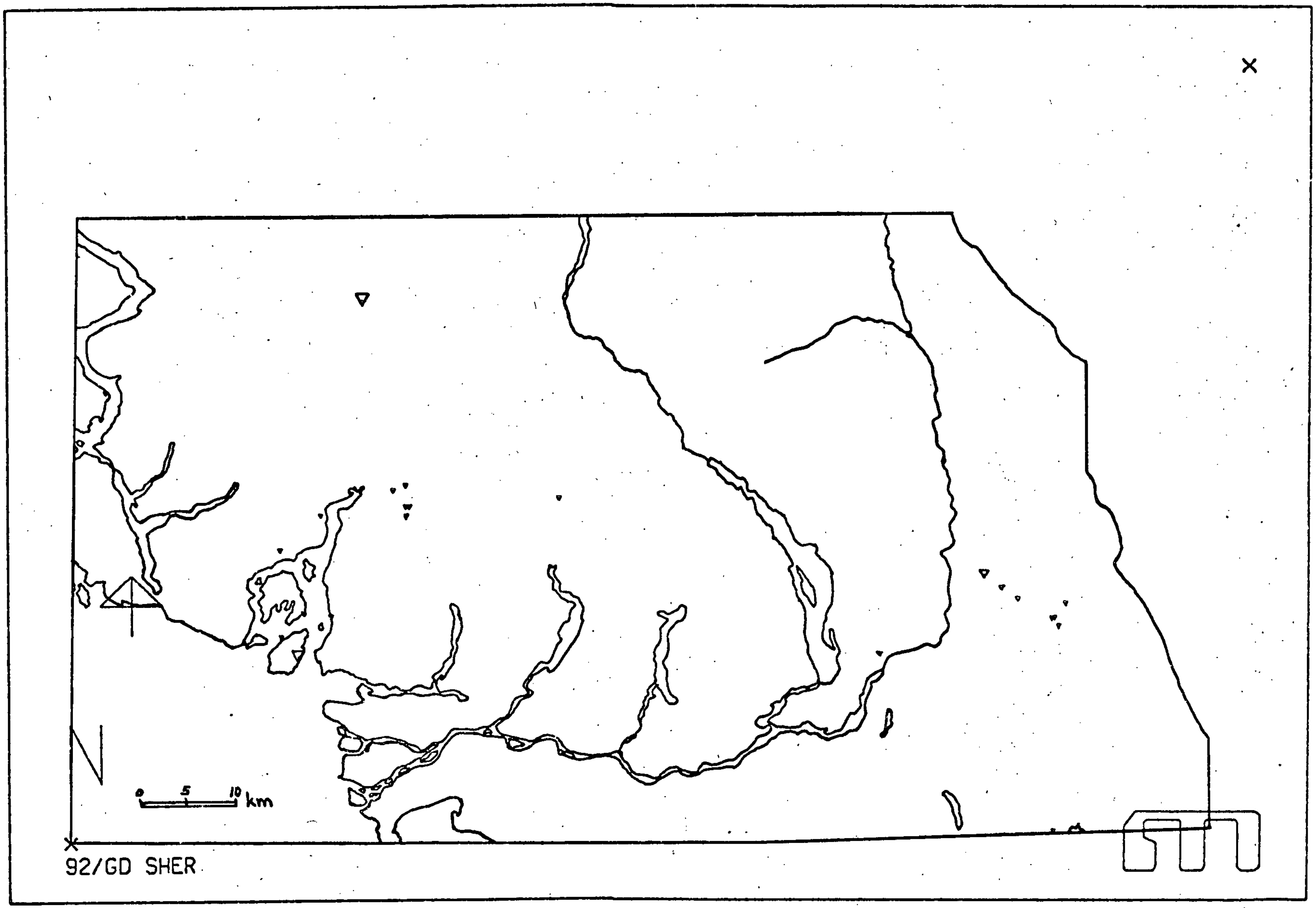
Symbol size on all maps is determined as follows:

Magnitude (Table 4-2)	Size
I	
II	
III	
IV	

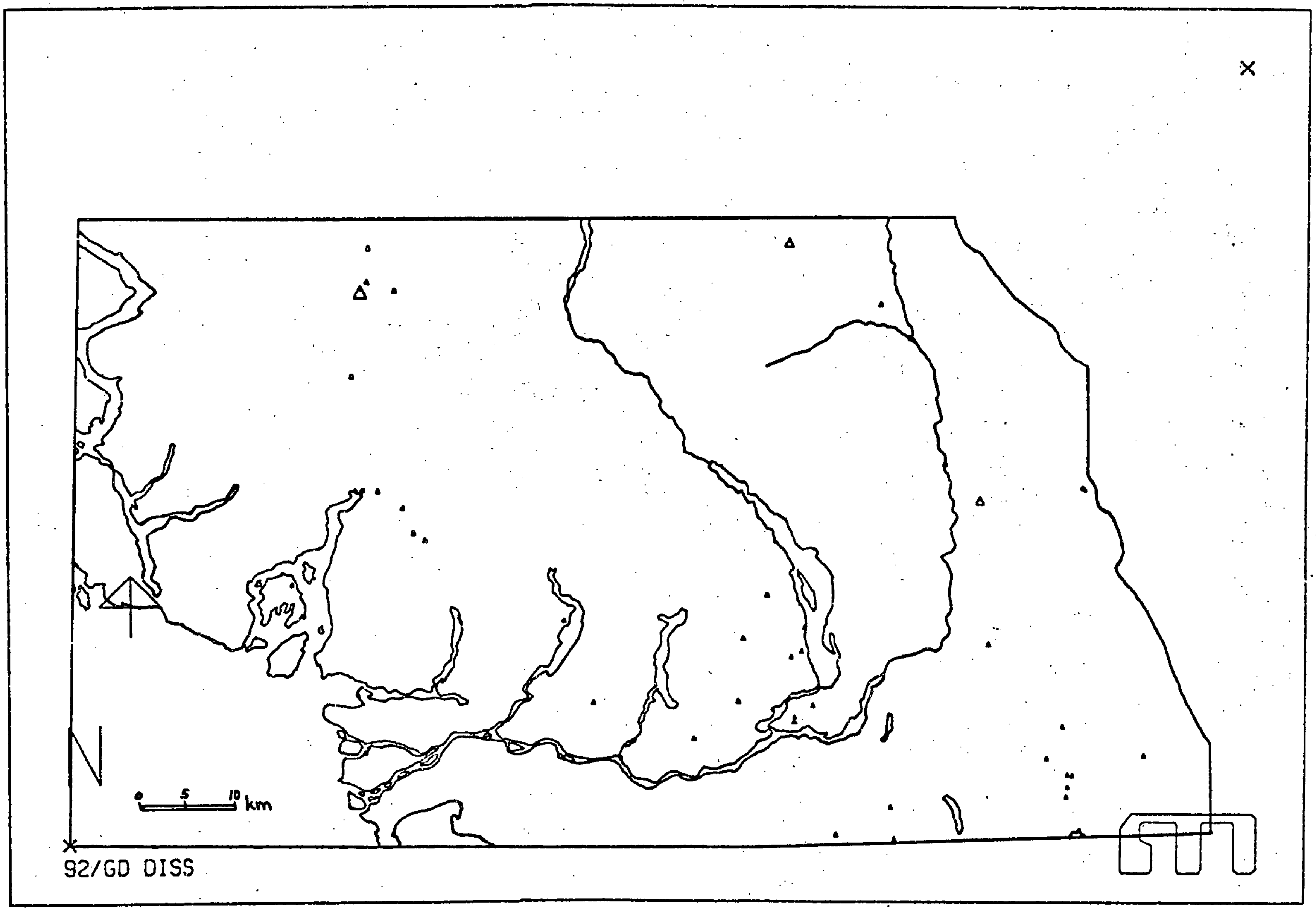
Note: All maps in this appendix are Xerox reductions of original Calcomp plotter output; resulting distortion may have altered the accuracy of deposit locations.



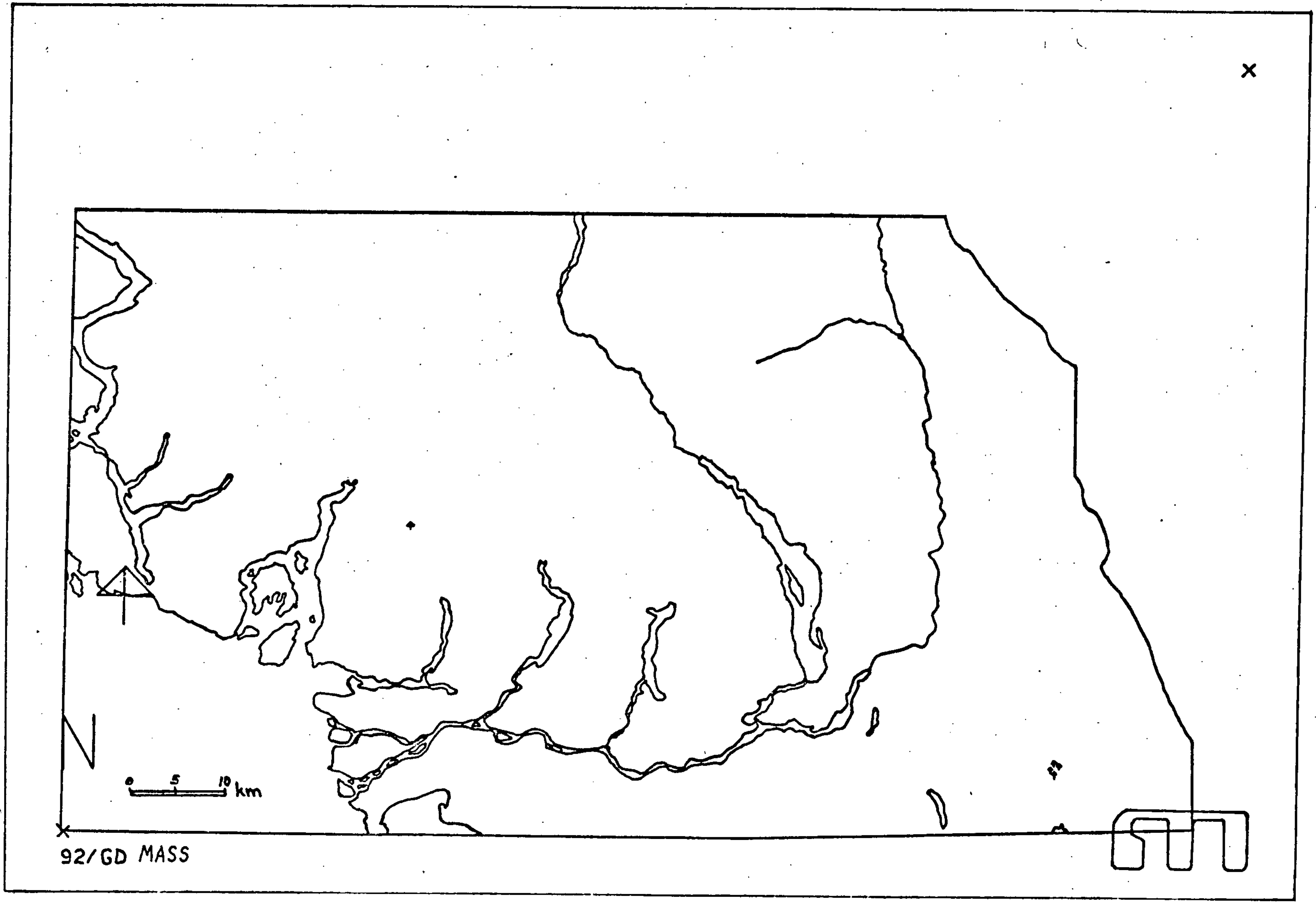
MAP B-1. Distribution of Vein Deposits



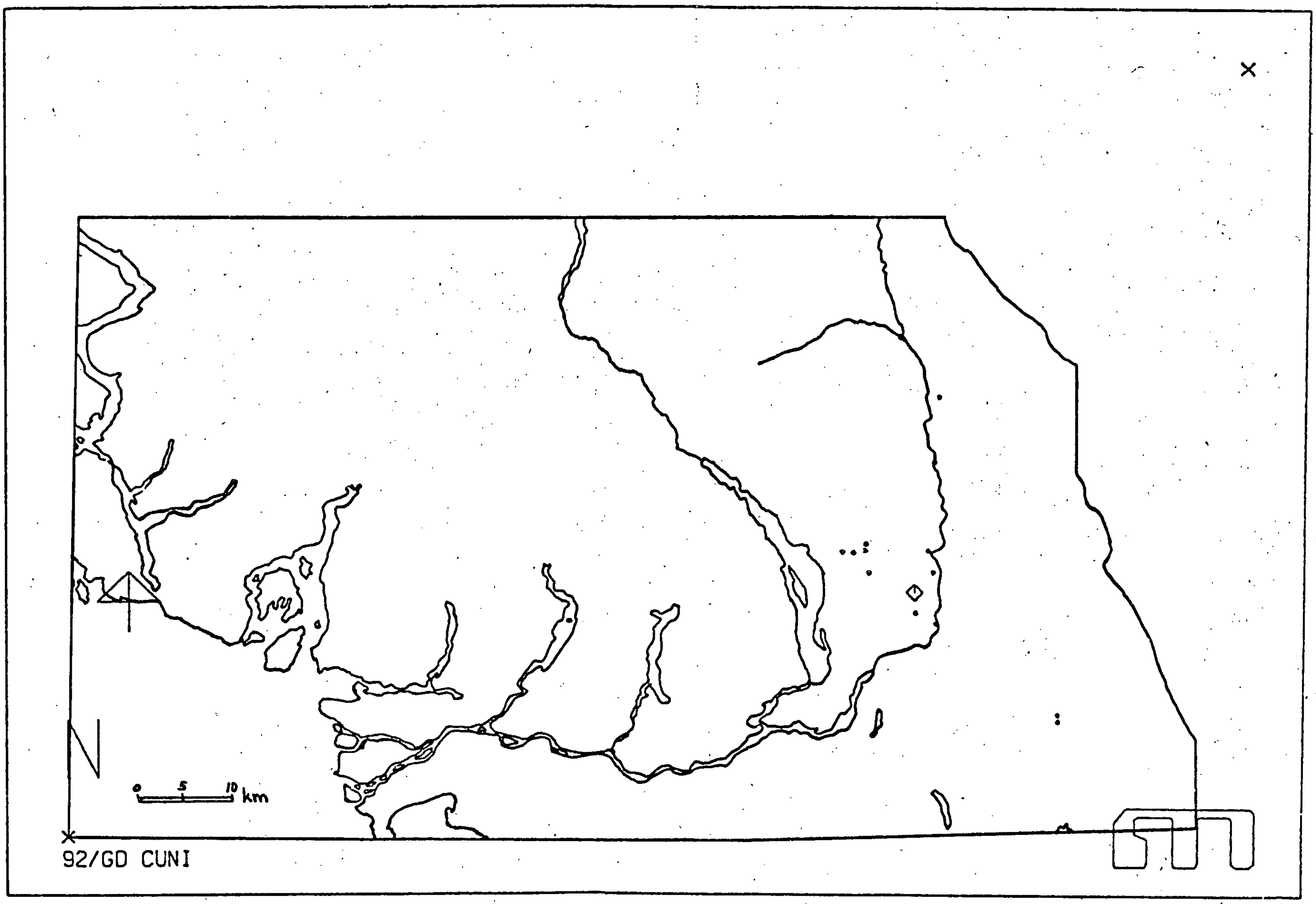
MAP B-2. Distribution of Shear Deposits



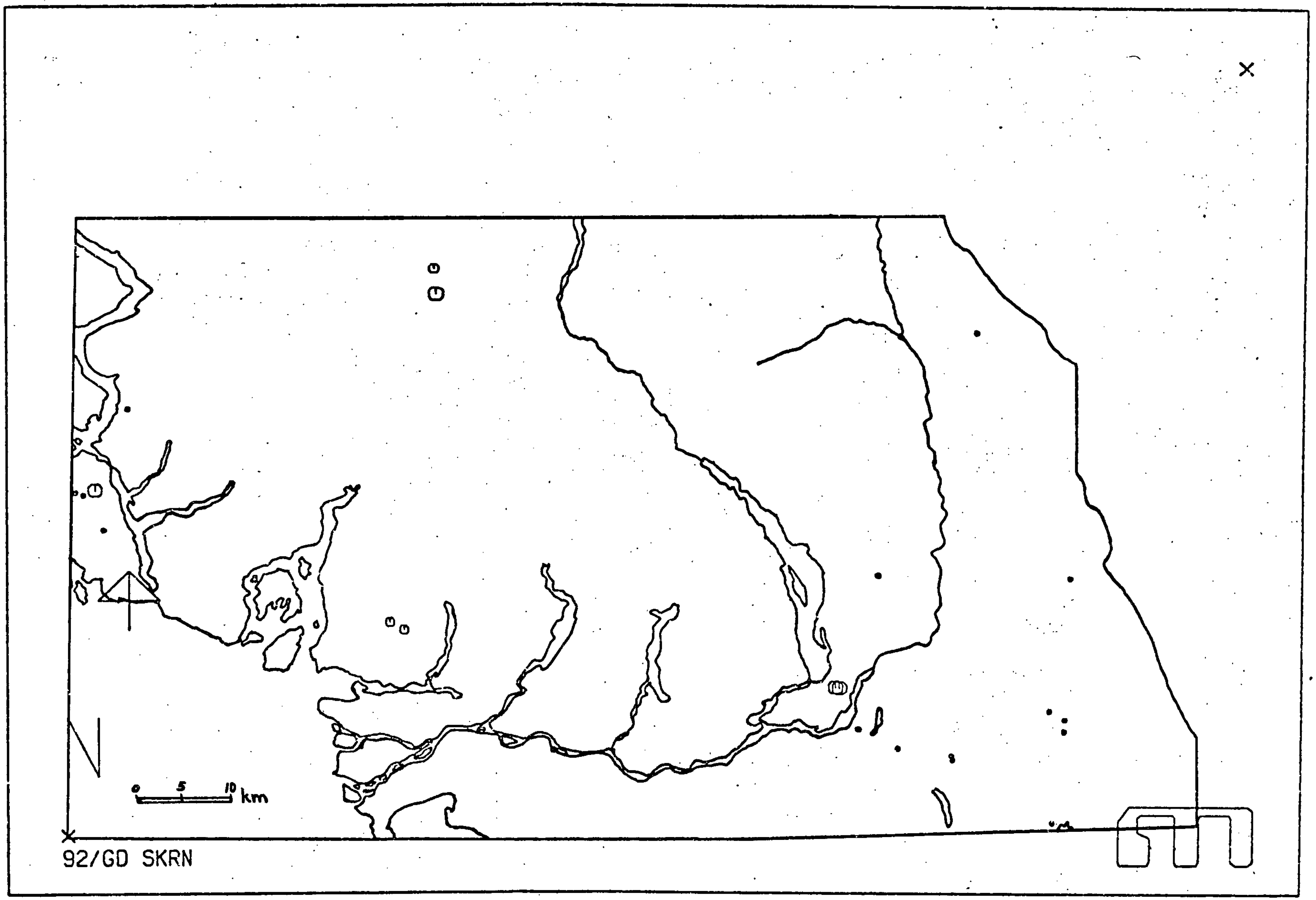
MAP B-3. Distribution of Disseminated Deposits



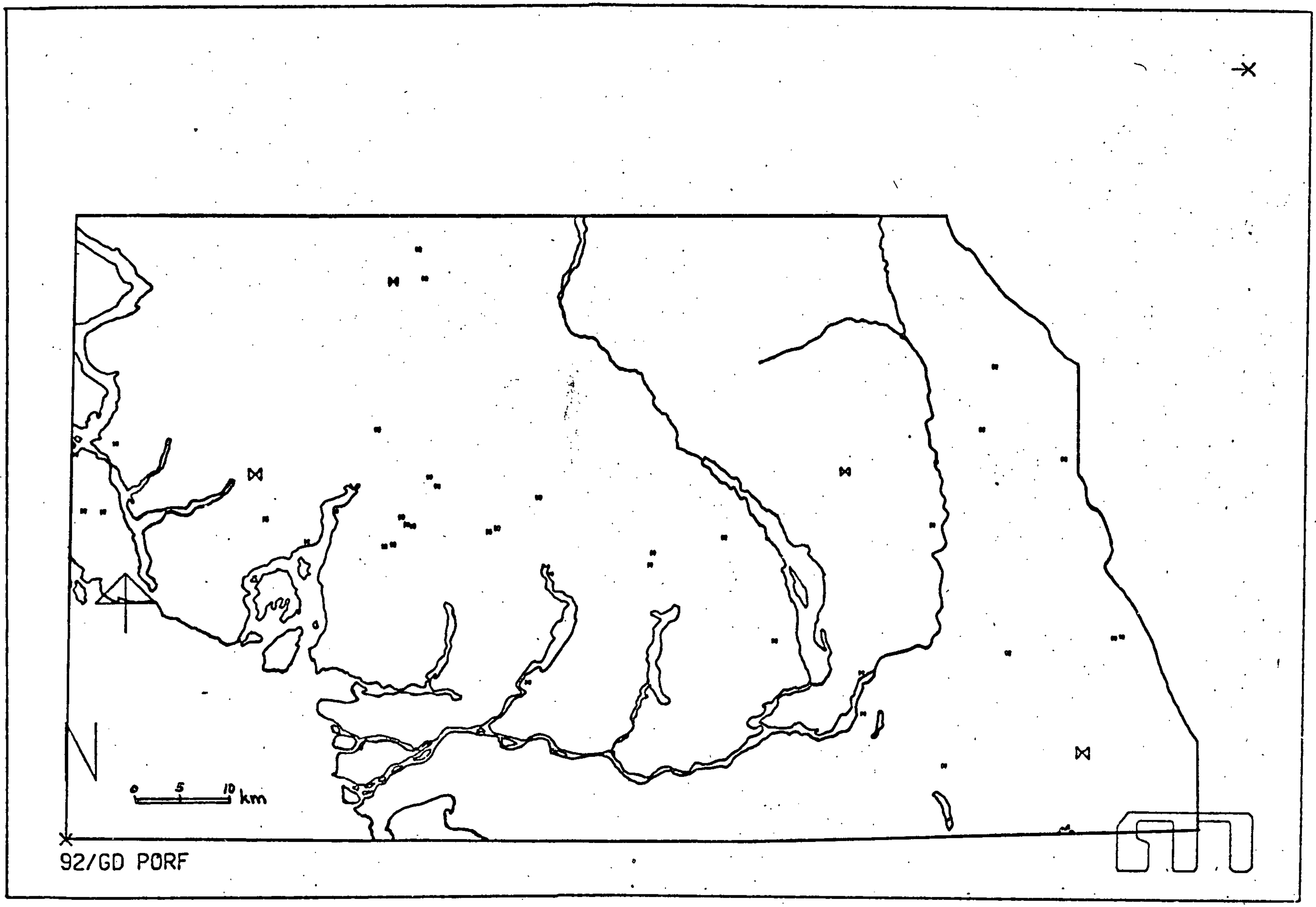
MAP B-4. Distribution of Massive Deposits



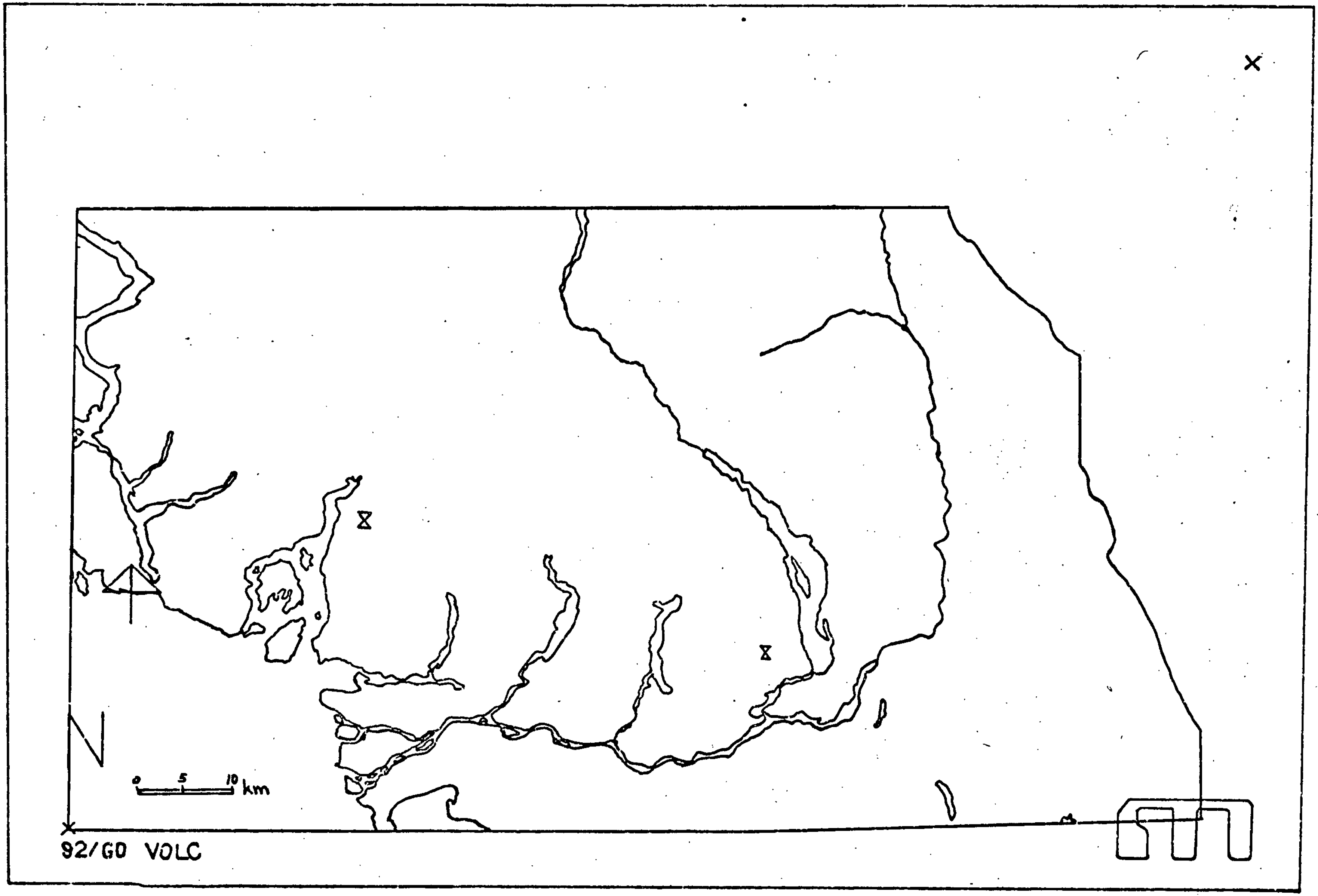
MAP B-5. Distribution of Magmatic Deposits



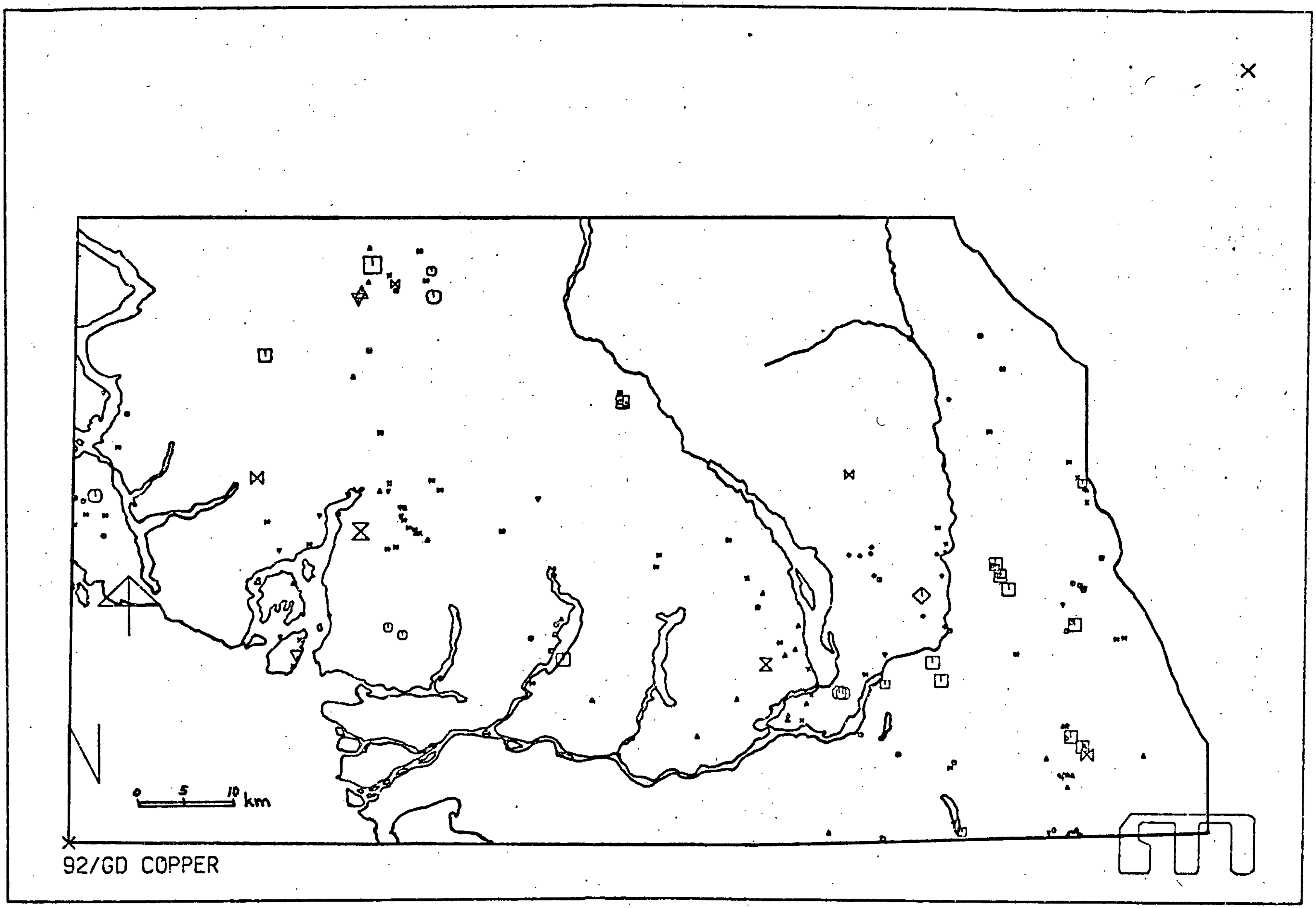
MAP B-6. Distribution of Skarn Deposits



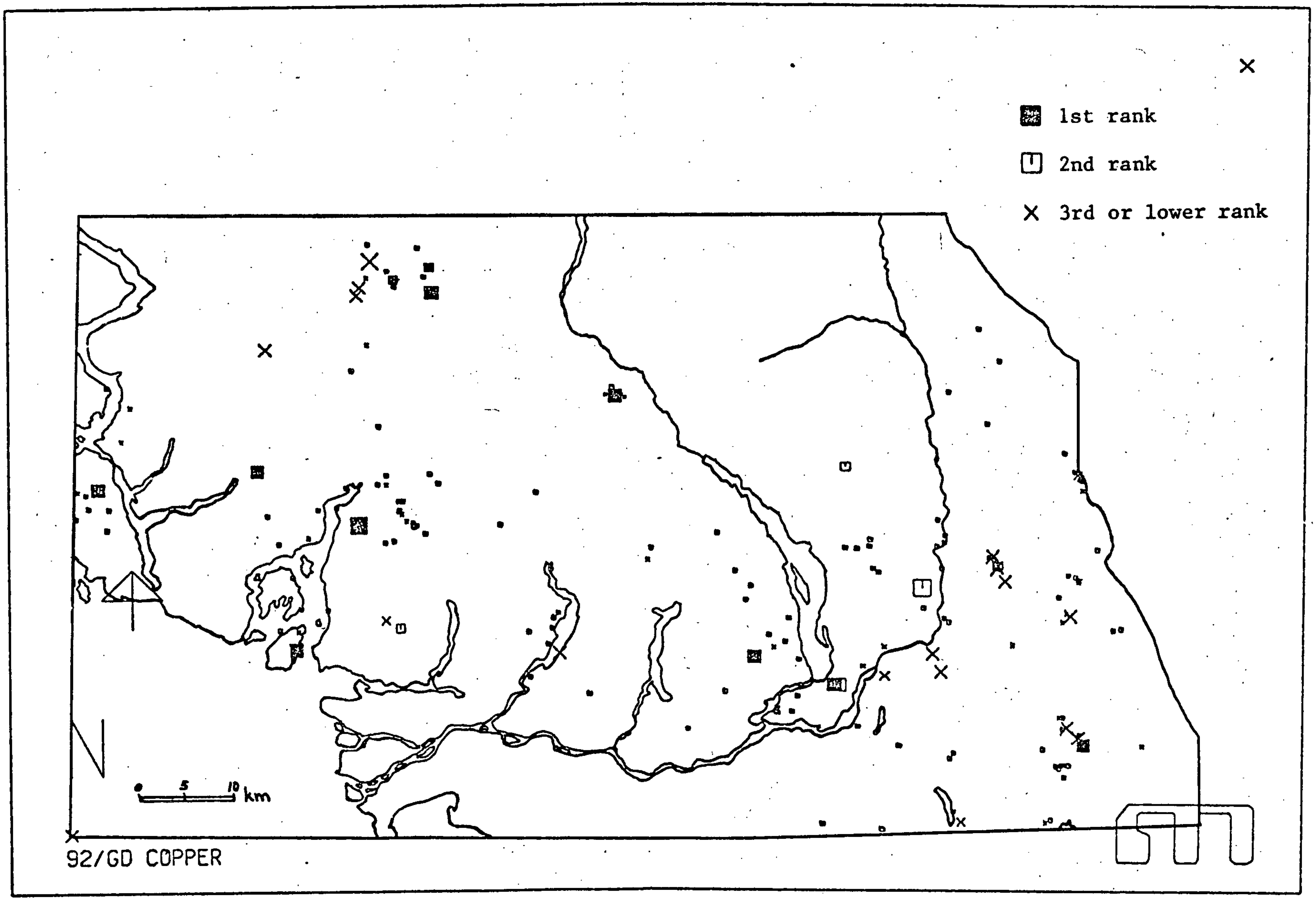
MAP B-7. Distribution of Porphyry Deposits



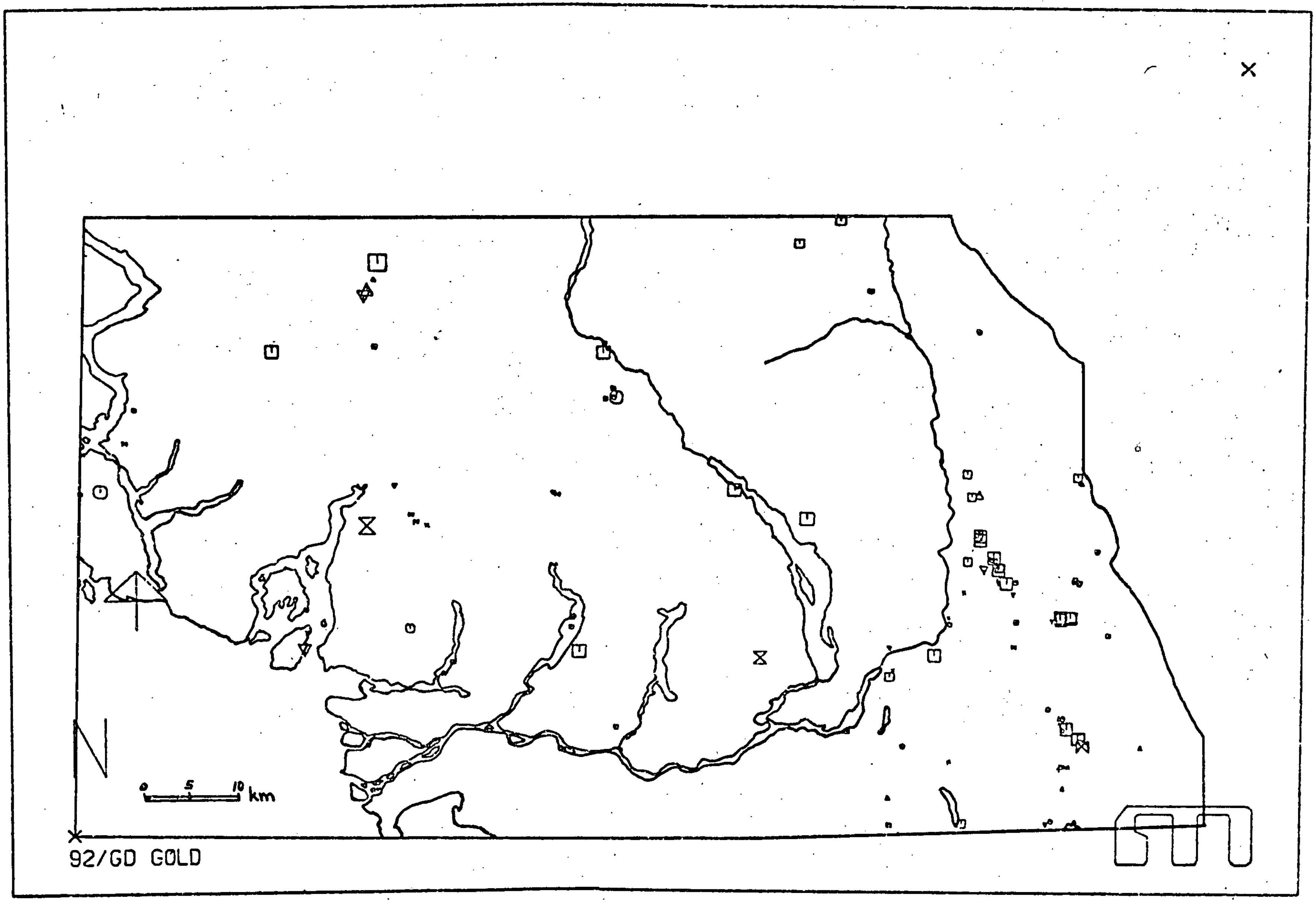
MAP B-8. Distribution of Volcanogenic Deposits



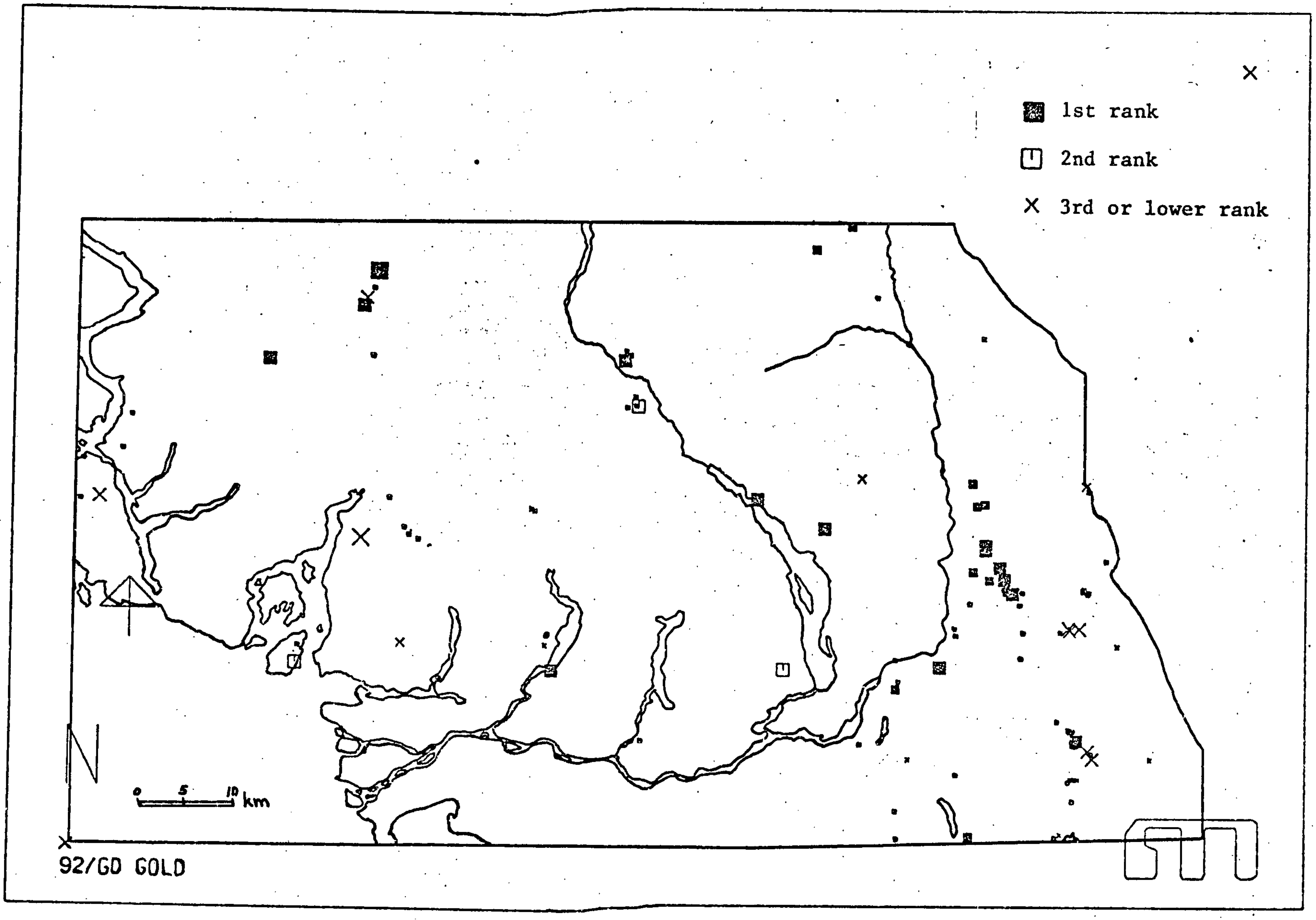
MAP B-9. Distribution of all Copper Occurrences (regardless of rank)



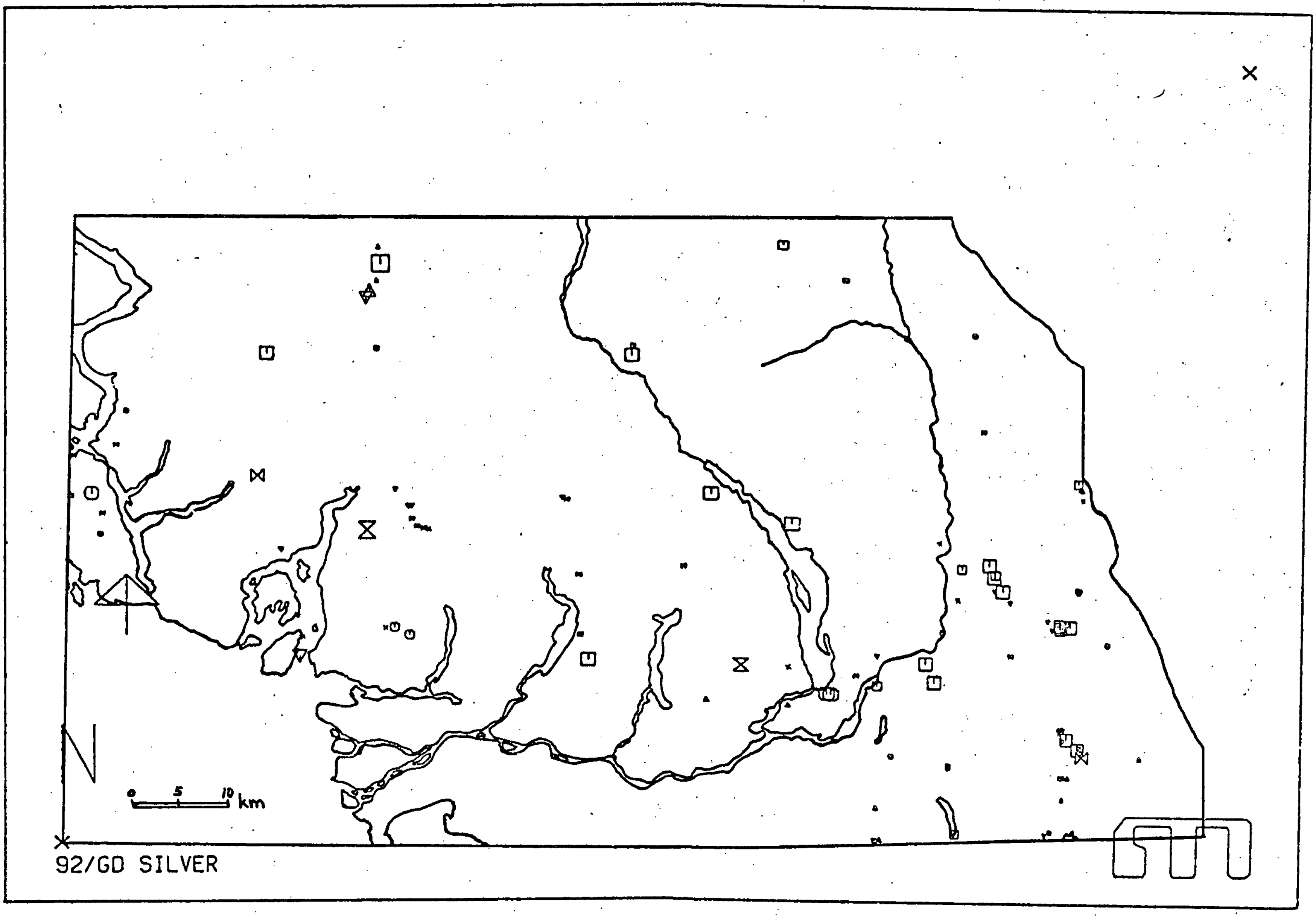
MAP B-10. Distribution of Copper Occurrences (according to first, second or lower rank)



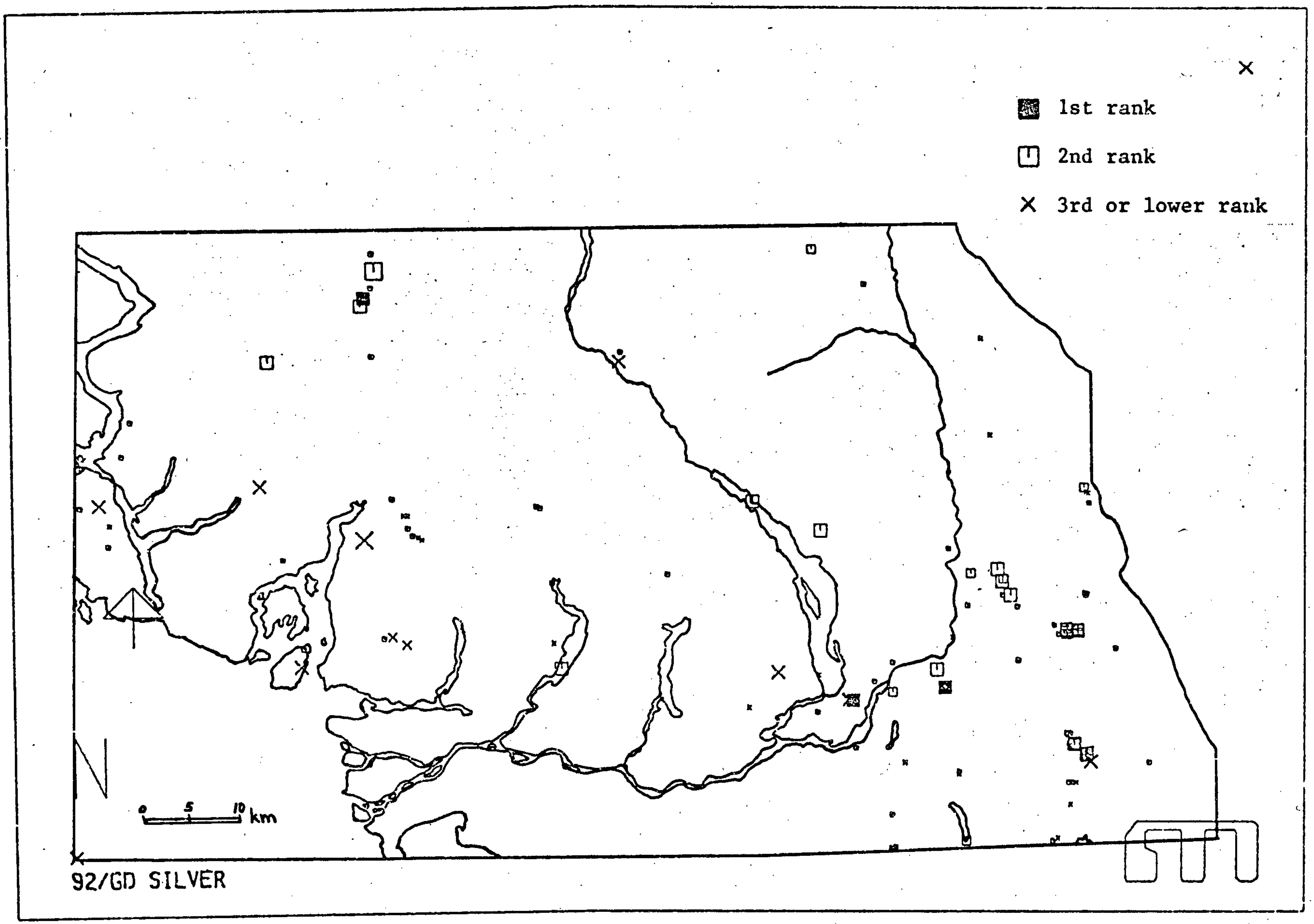
MAP B-11. Distribution of all Gold Occurrences (regardless of rank)



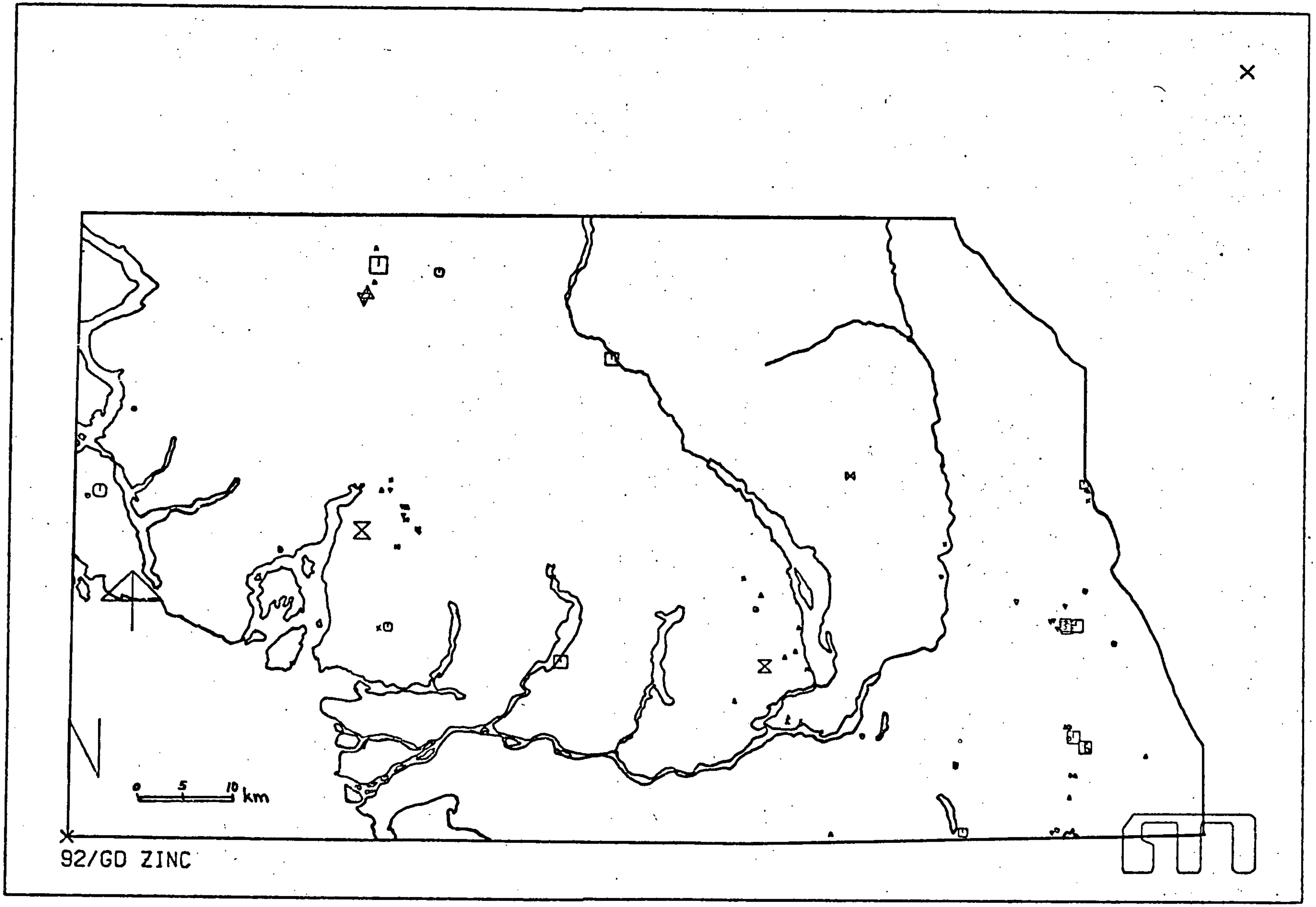
MAP B-12. Distribution of Gold Occurrences (according to first, second or lower rank)



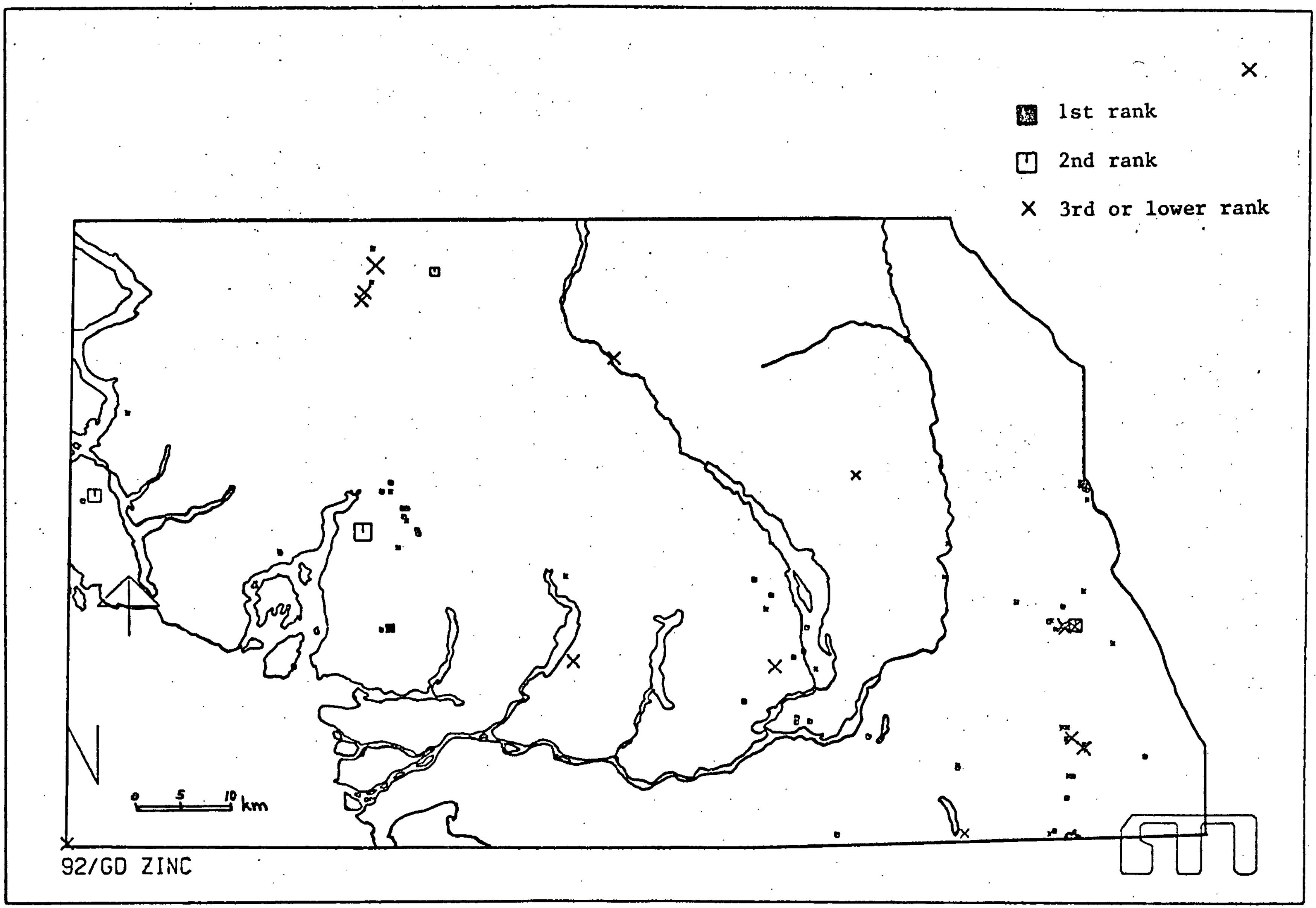
MAP B-13. Distribution of all Silver Occurrences (regardless of rank)



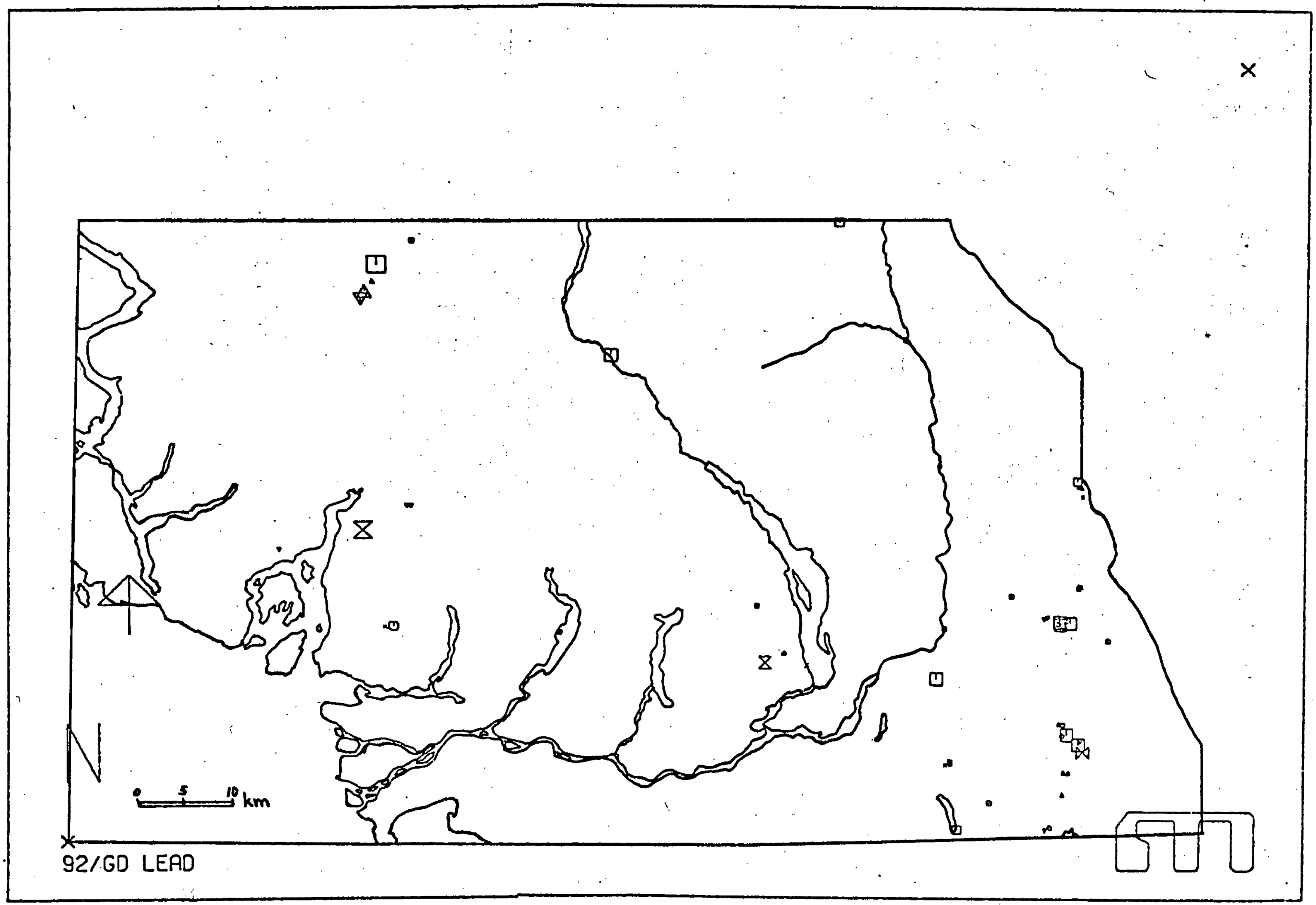
MAP B-14. Distribution of Silver Occurrences (according to first, second or lower rank)



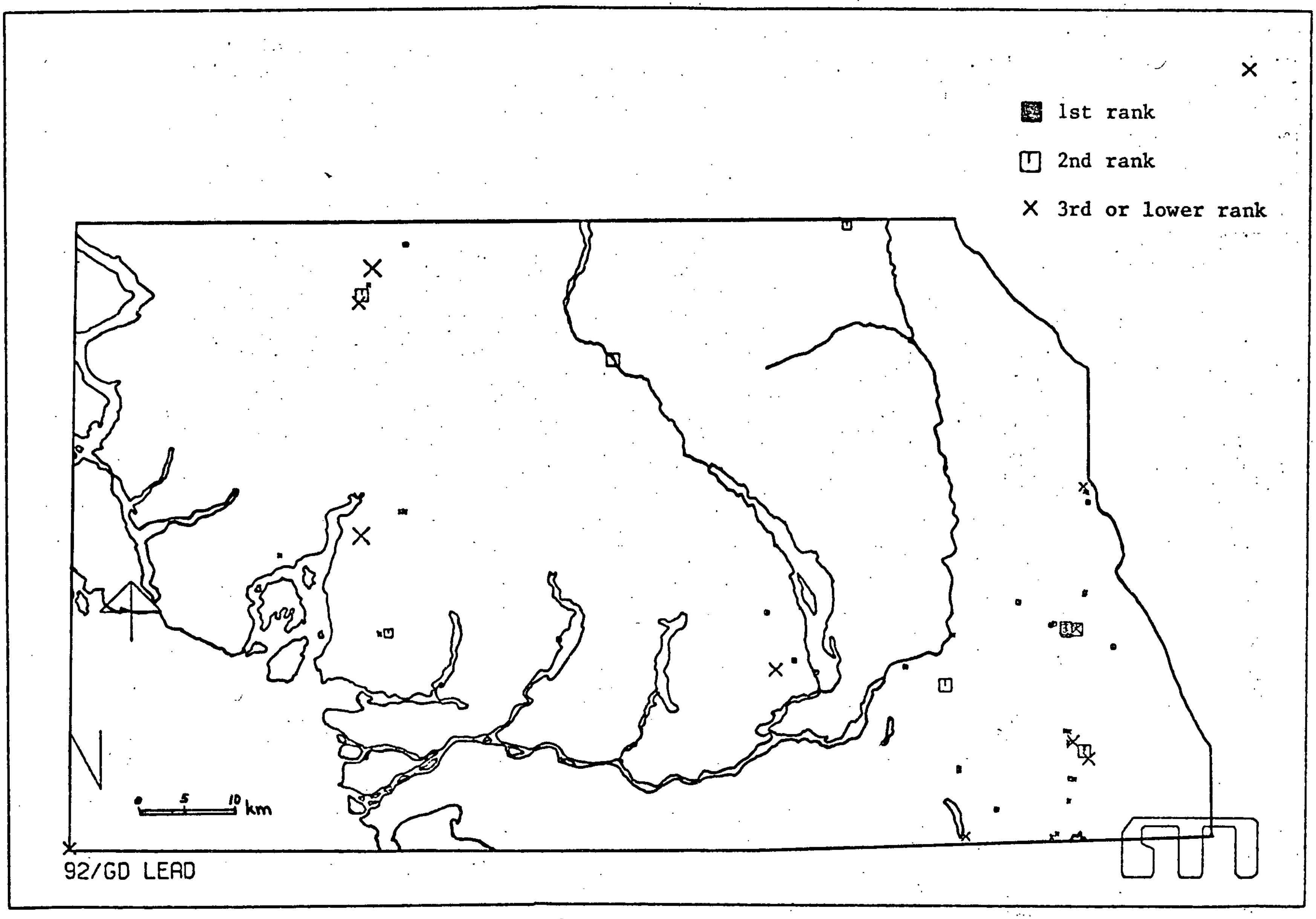
MAP B-15. Distribution of all Zinc Occurrences (regardless of rank)



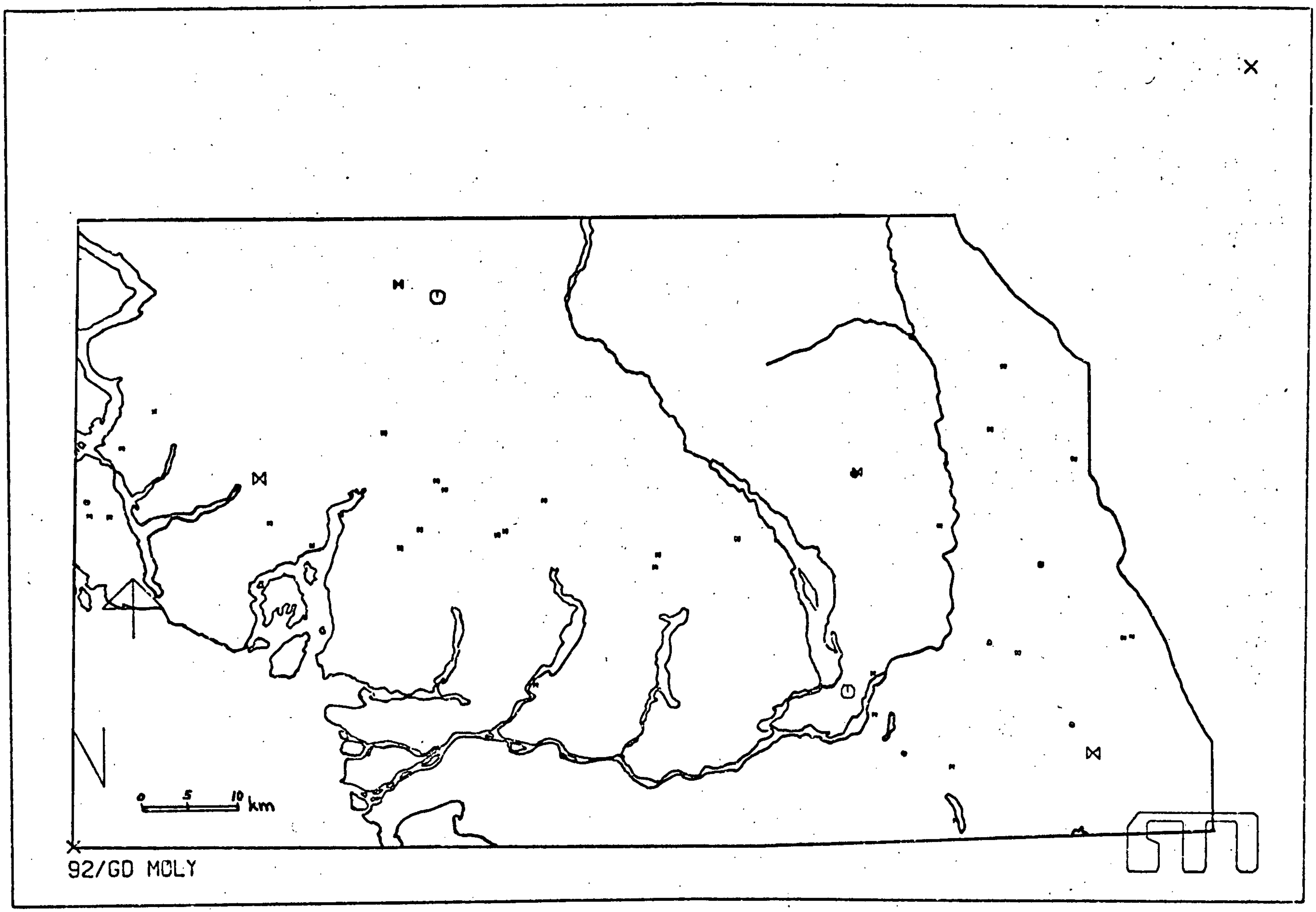
MAP B-16. Distribution of Zinc Occurrences (according to first, second or lower rank)



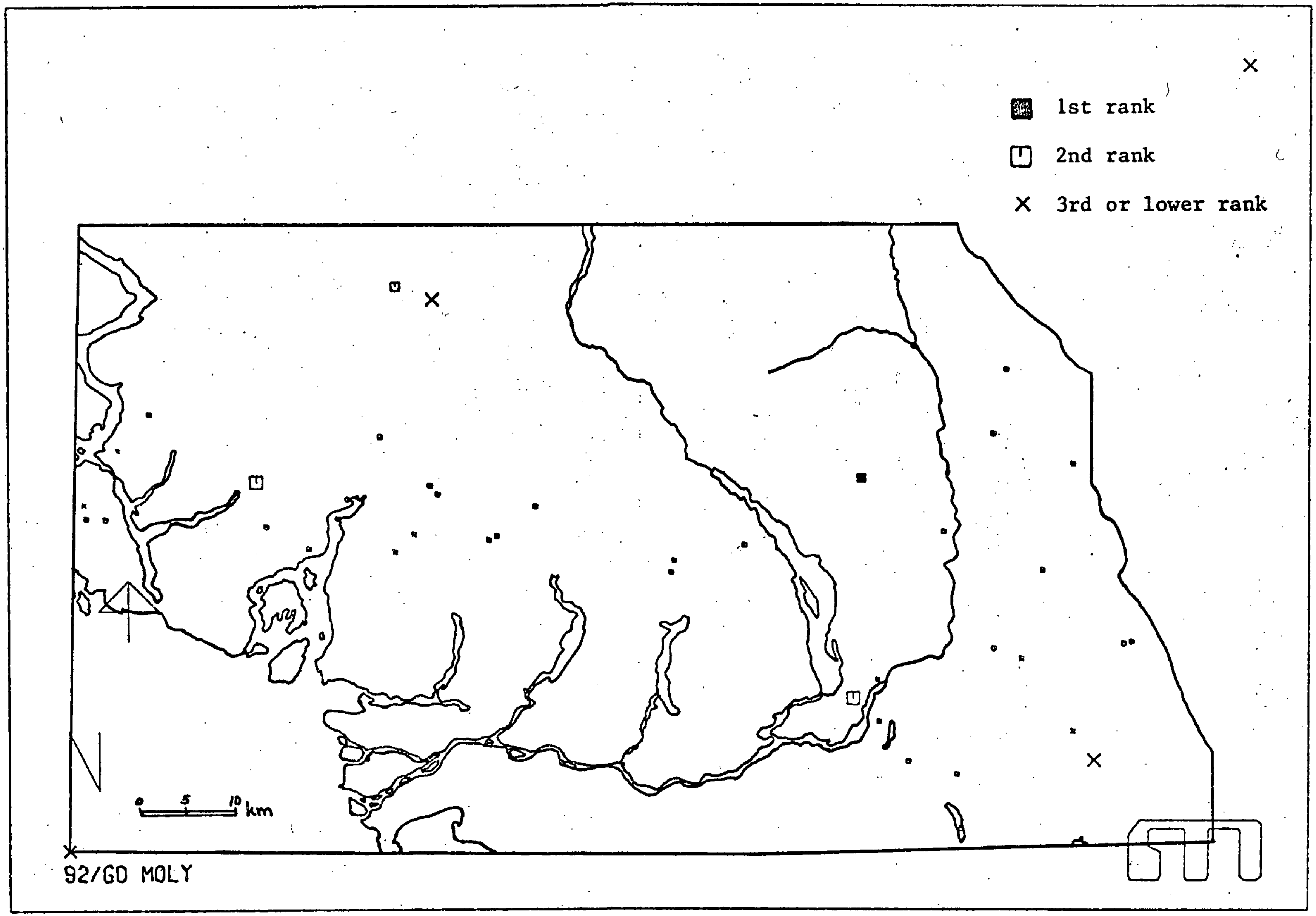
MAP B-17. Distribution of all Lead Occurrences (regardless of rank)



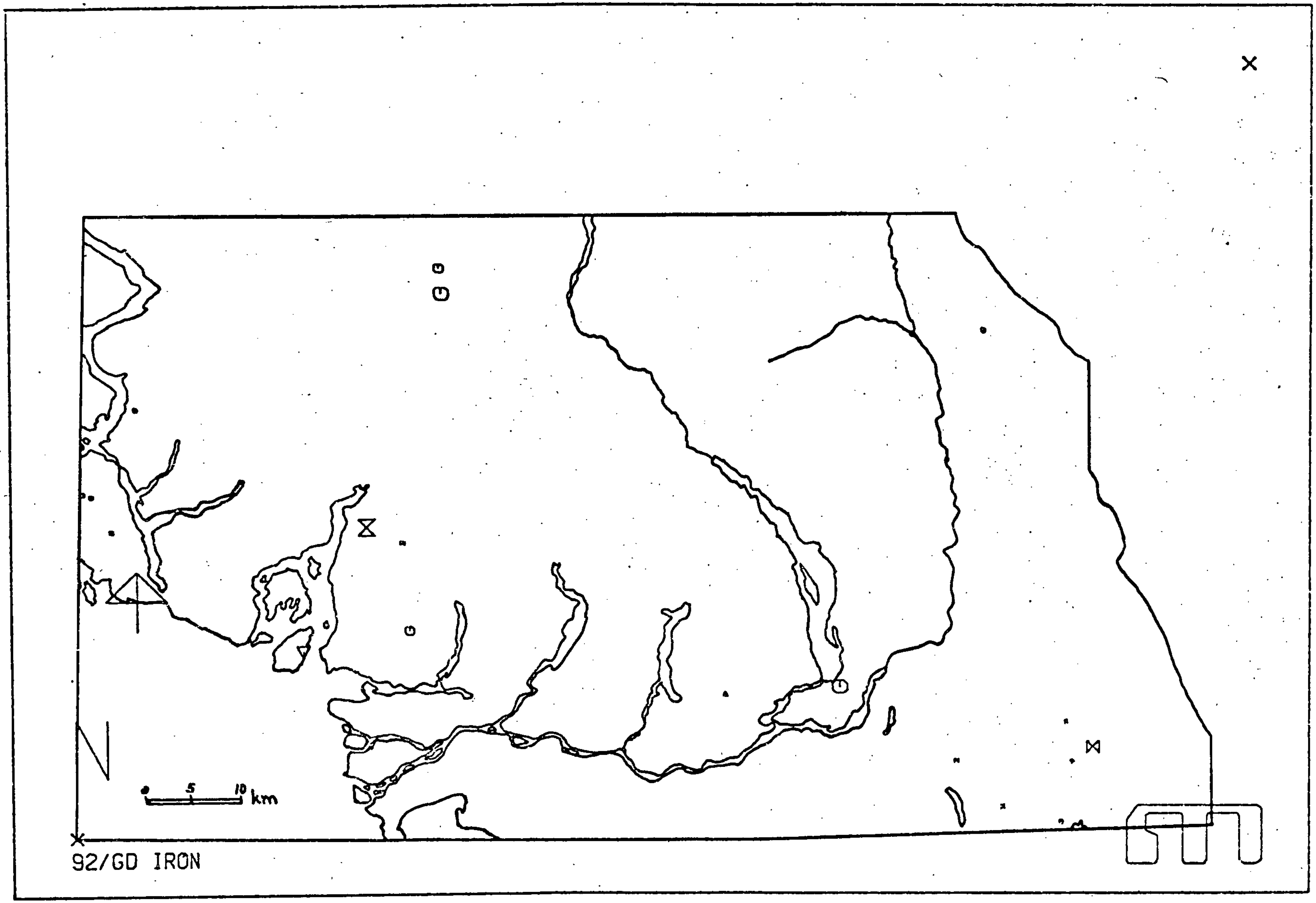
MAP B-18. Distribution of Lead Occurrences (according to first, second or lower rank)



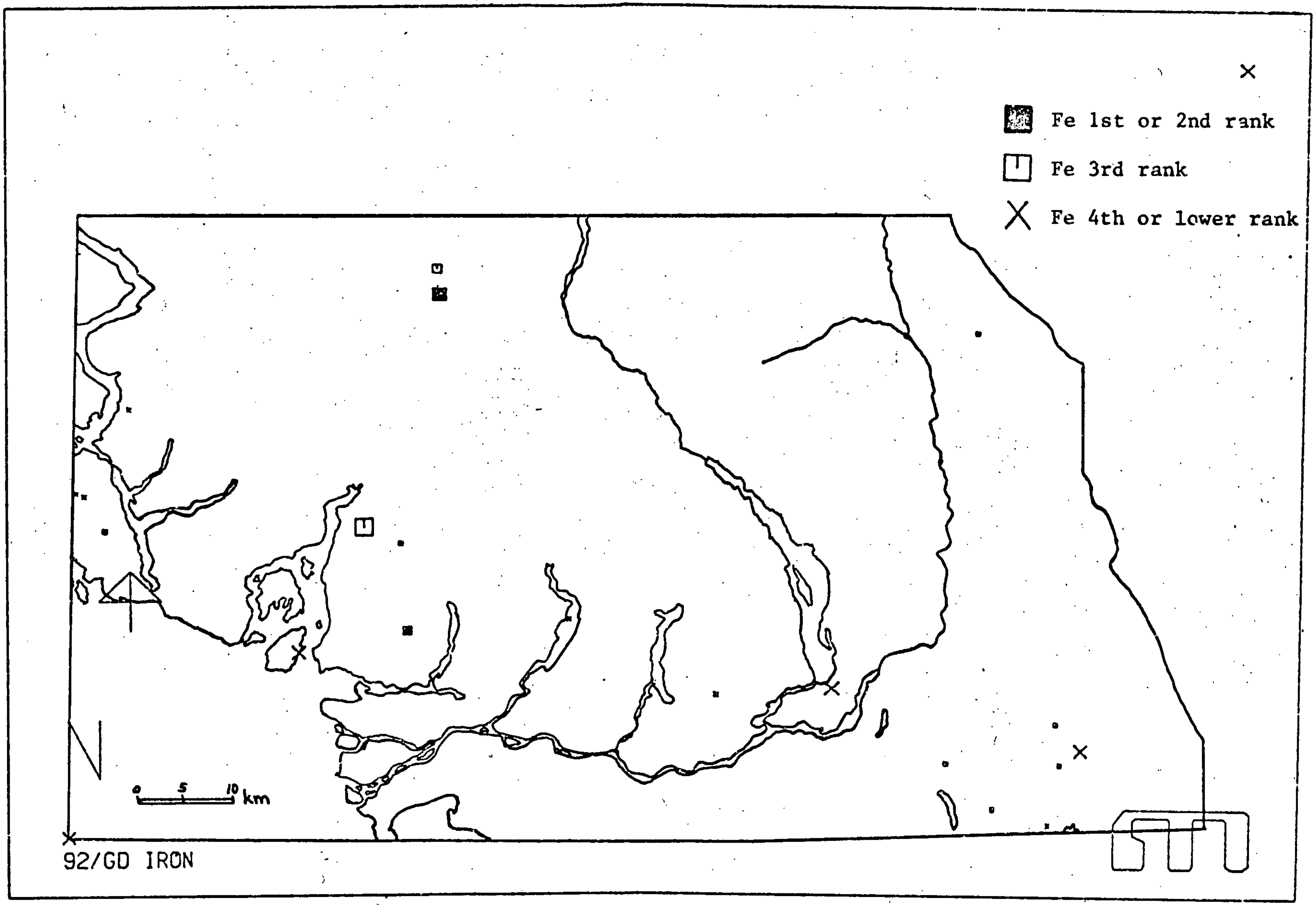
MAP B-19. Distribution of all Molybdenum Occurrences (regardless of rank)



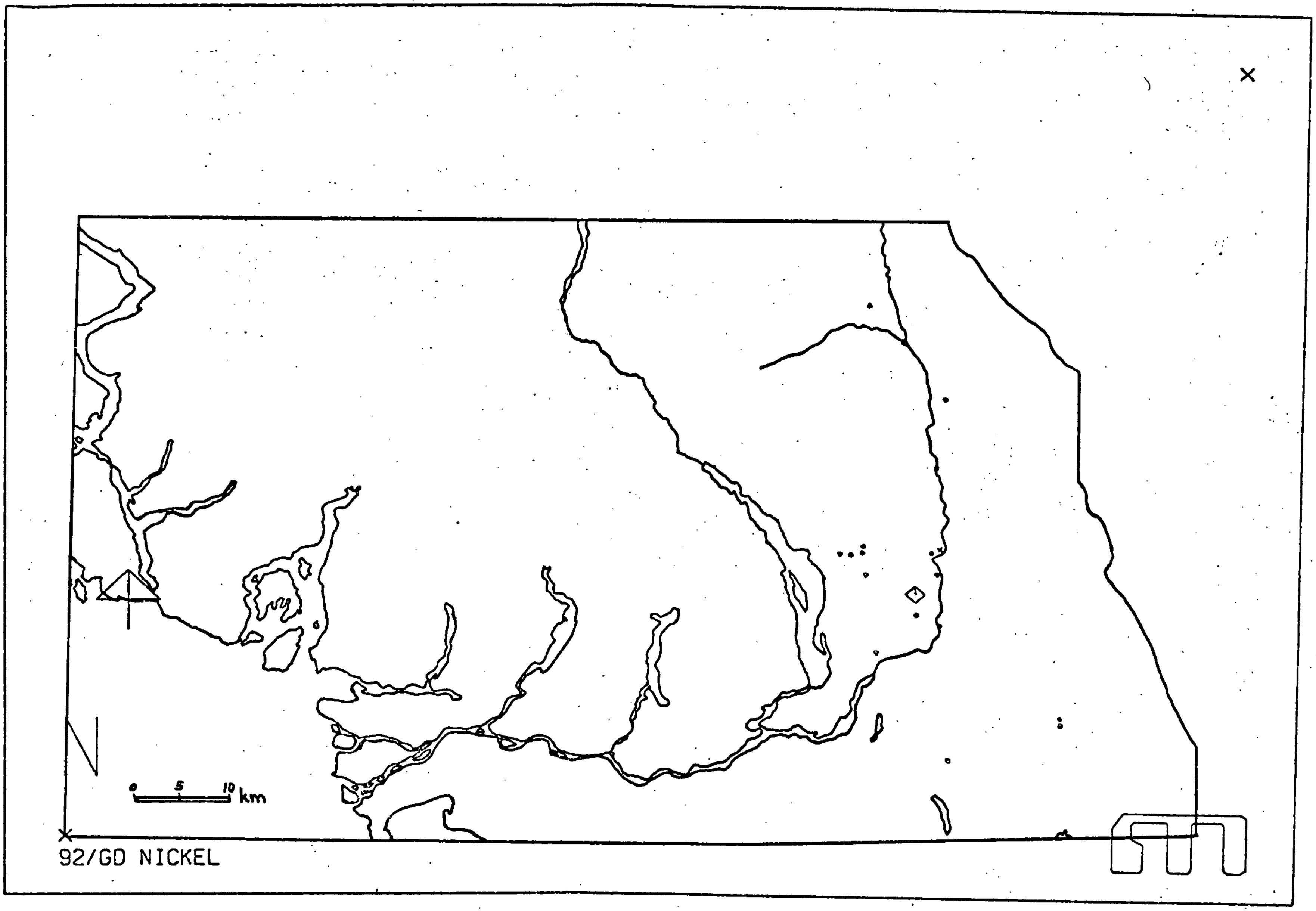
MAP B-20. Distribution of Molybdenum Occurrences (according to first, second or lower rank)



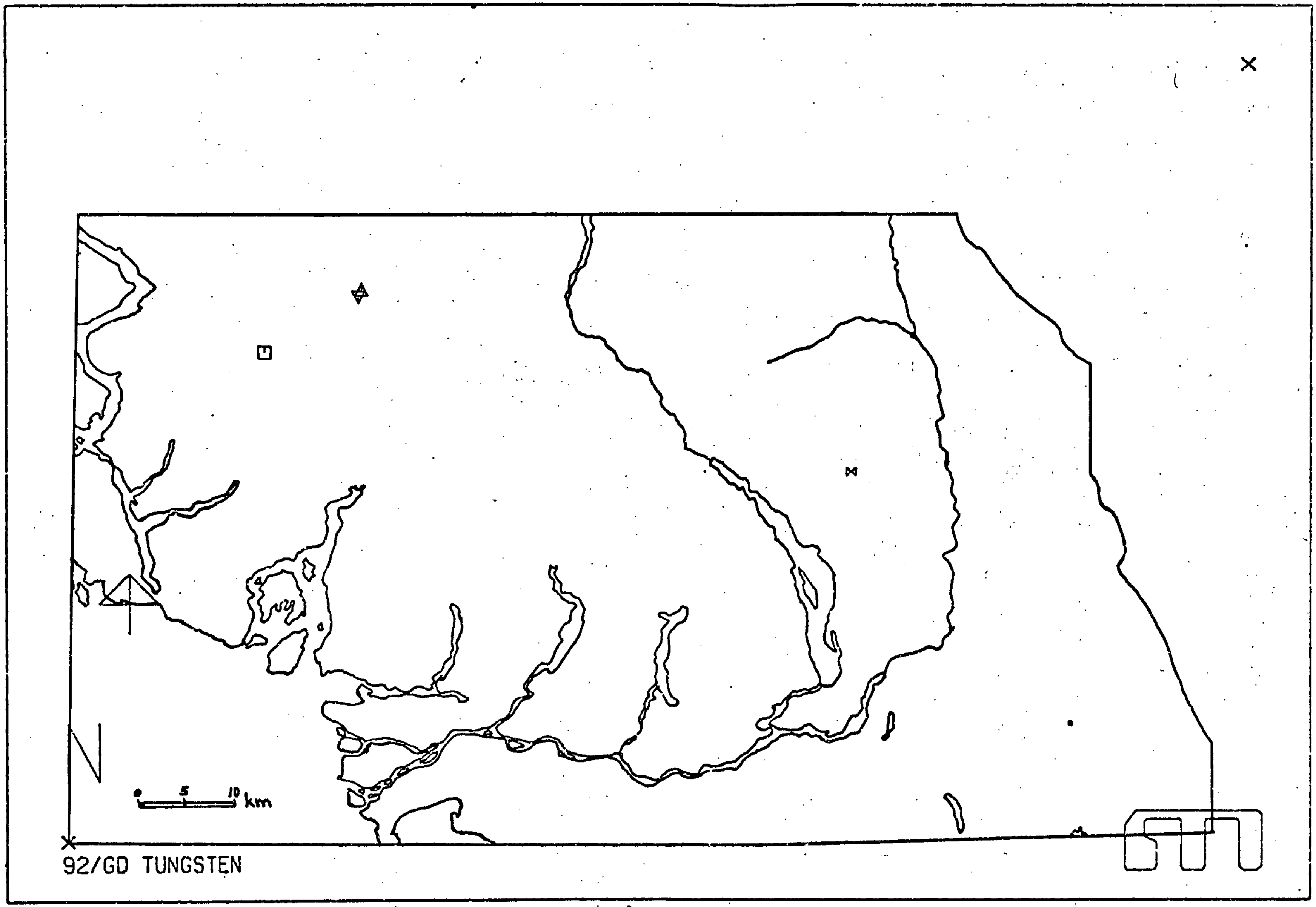
MAP B-21. Distribution of all Iron Occurrences (regardless of rank)



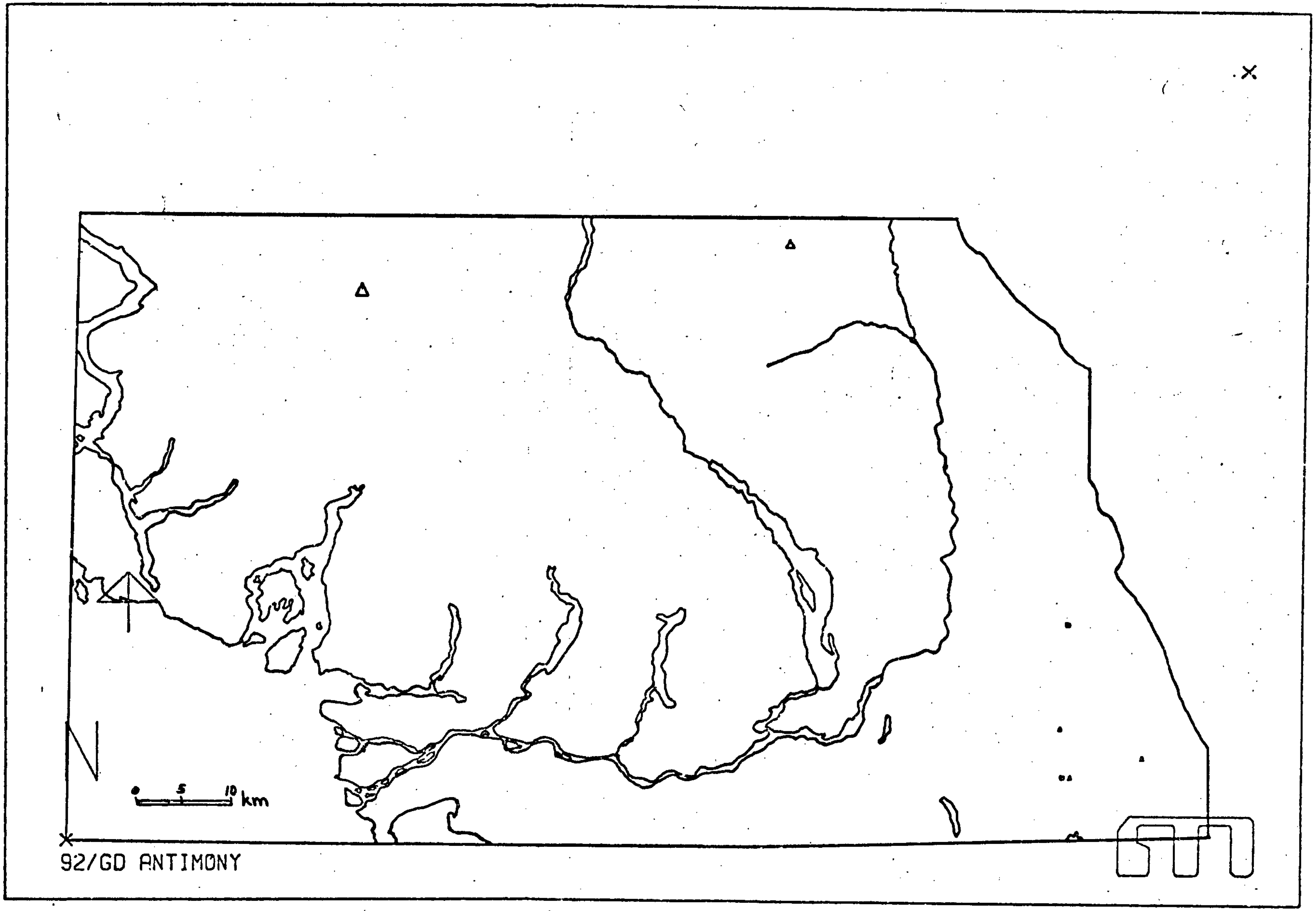
MAP B-22. Distribution of Iron Occurrences (according to first, second, third or lower rank)



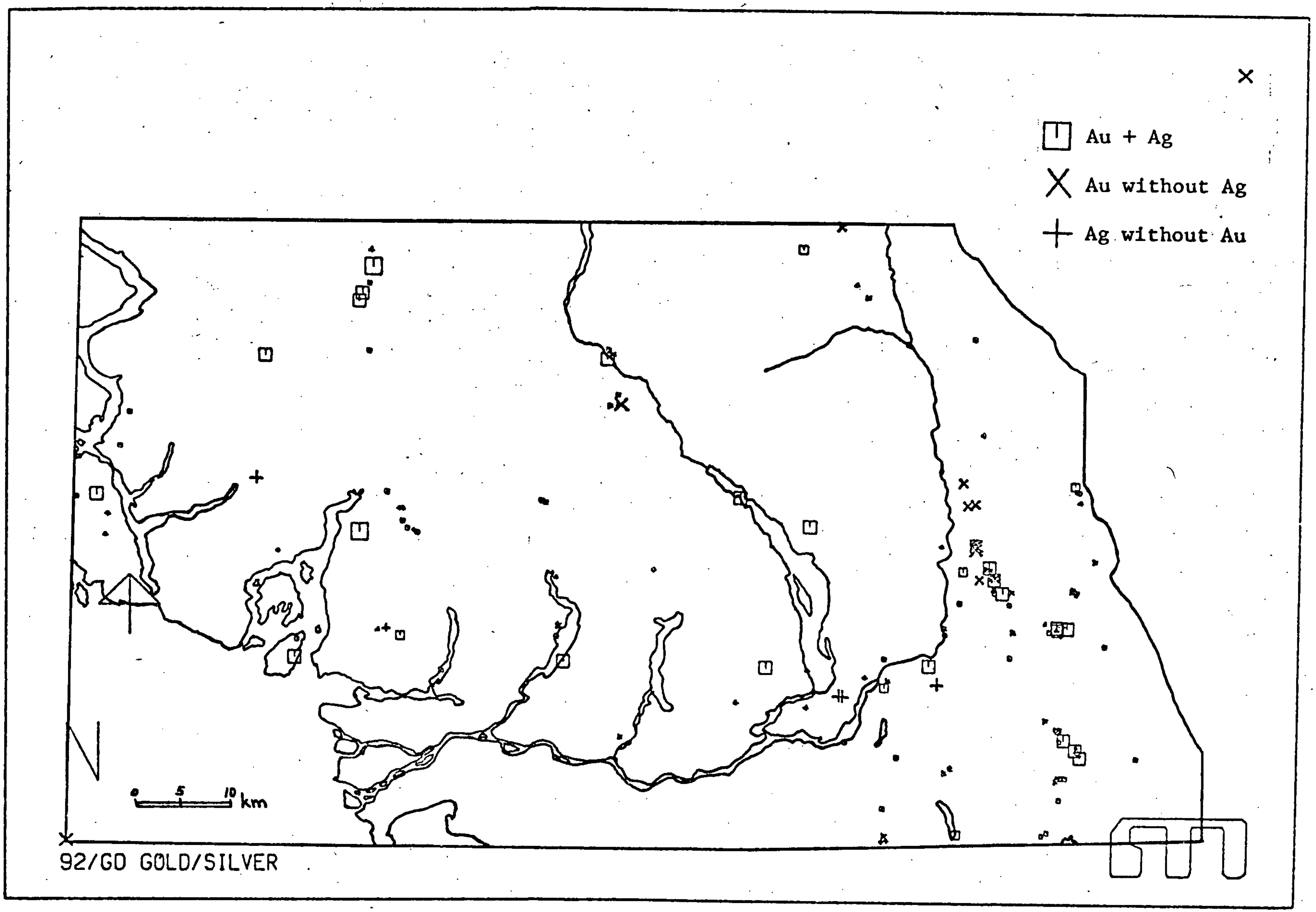
MAP B-23. Distribution of all Nickel Occurrences (regardless of rank)



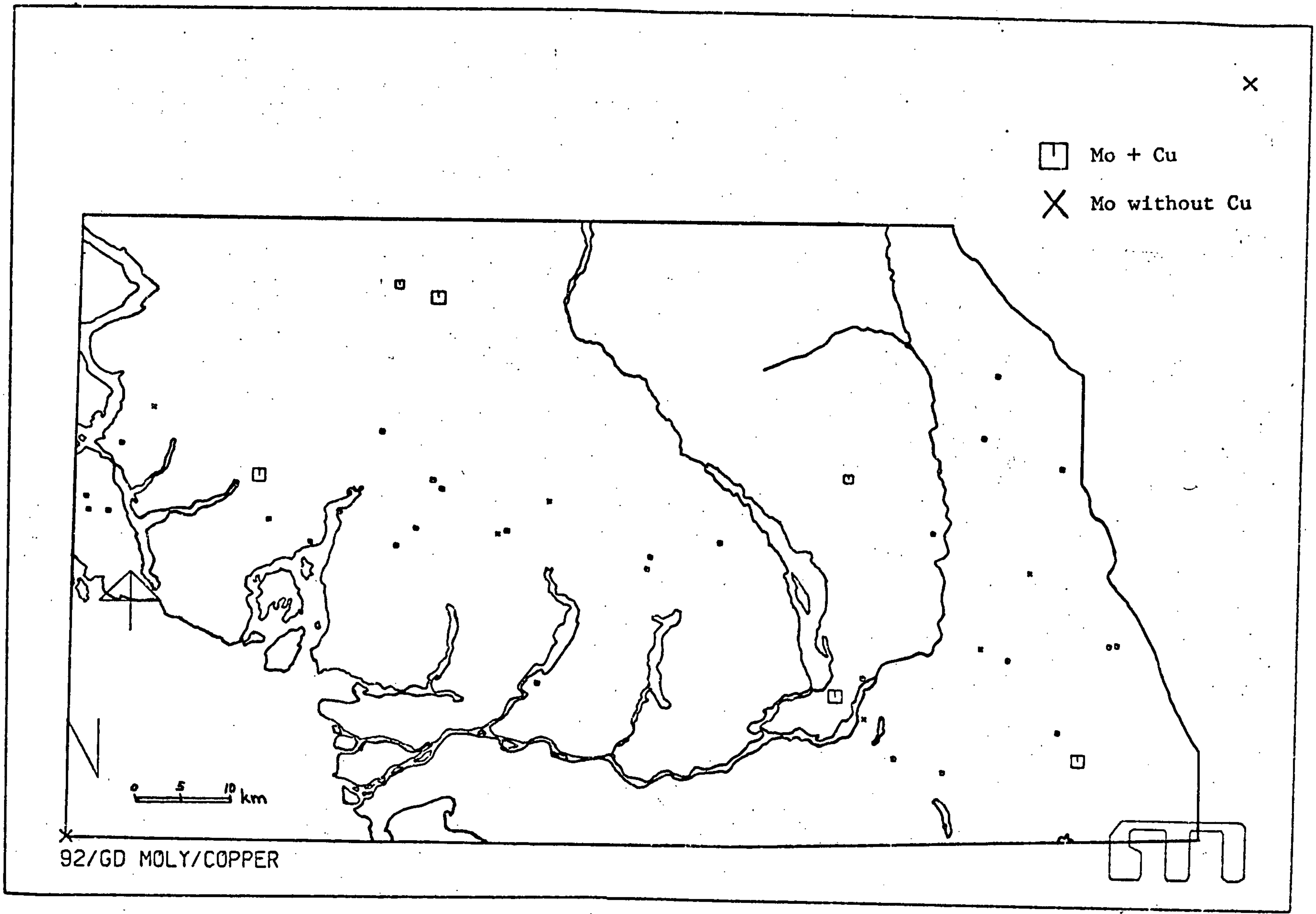
MAP B-24. Distribution of all Tungsten Occurrences (regardless of rank)



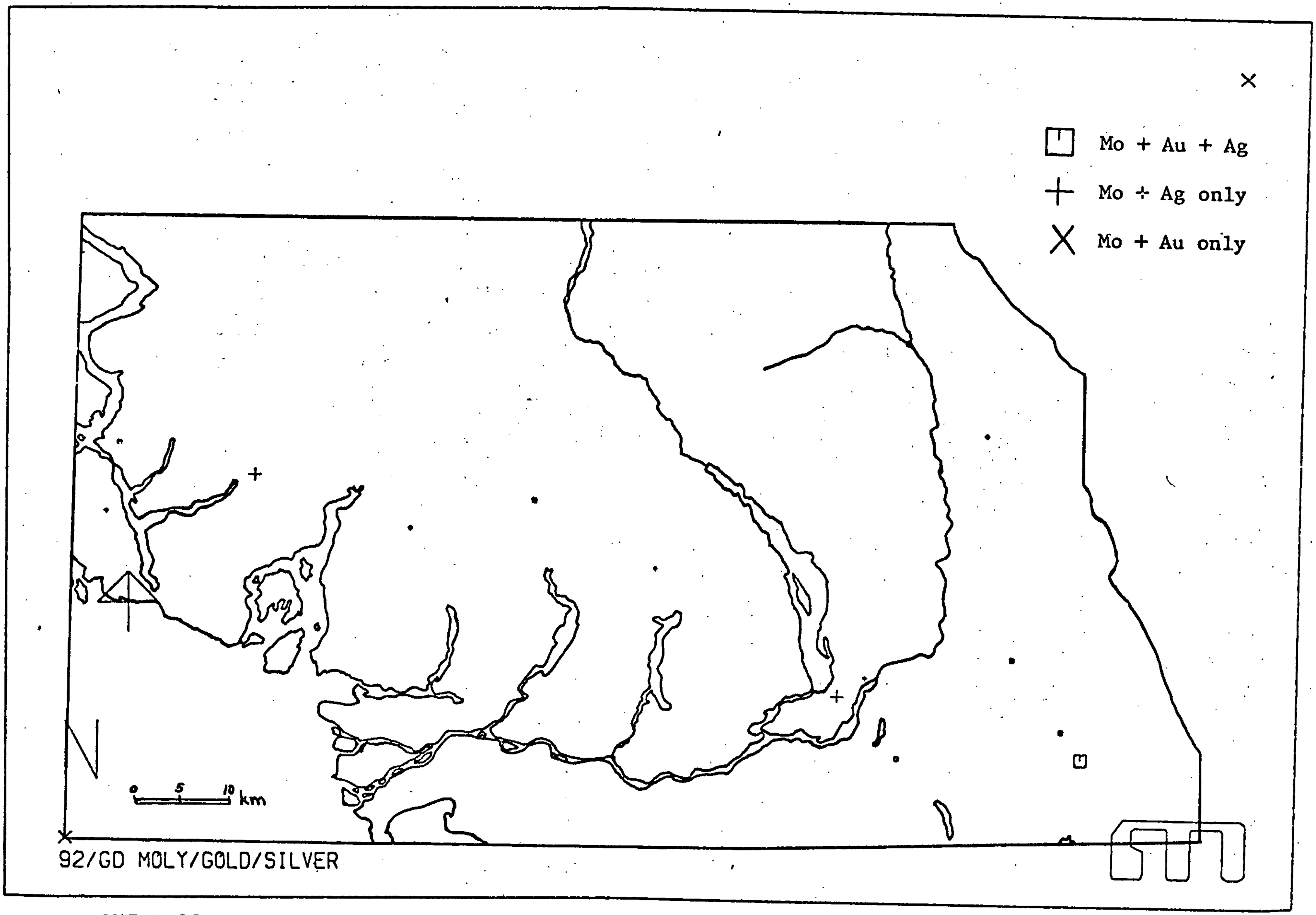
MAP B-25. Distribution of all Antimony Occurrences (regardless of rank)



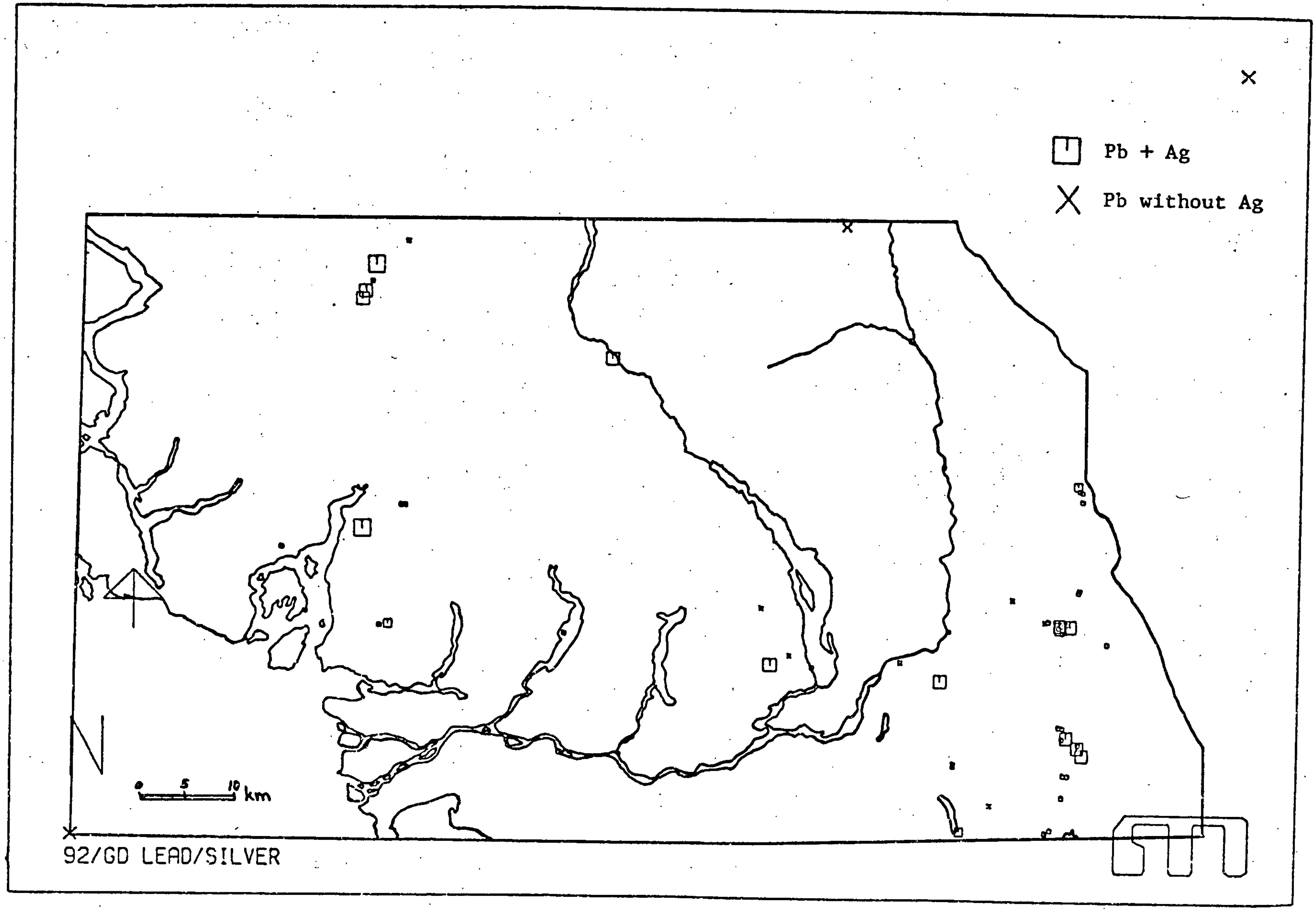
MAP B-26. Distribution Relationships Between Gold and Silver Occurrences



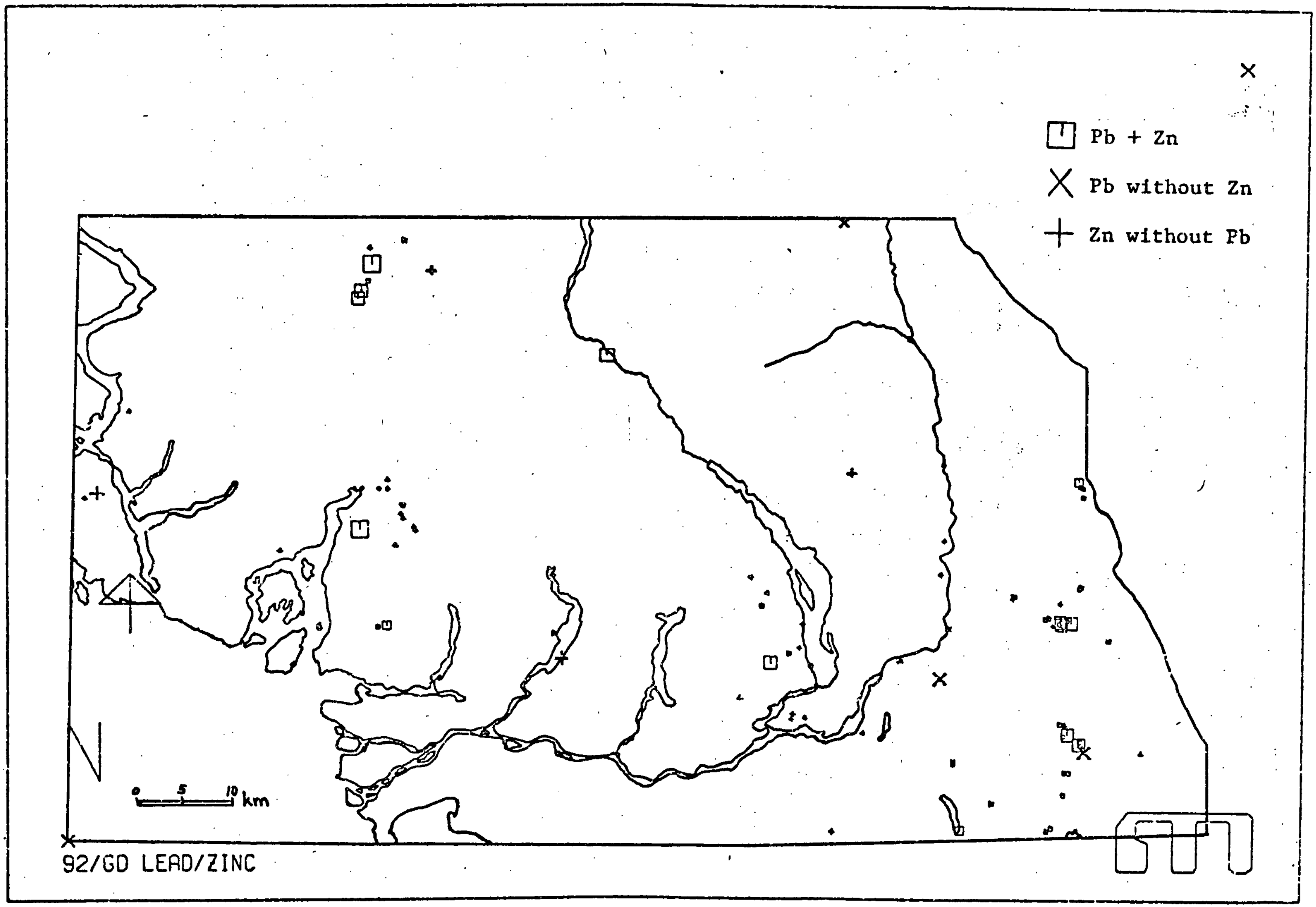
MAP B-27. Distribution Relationships Between Molybdenum and Copper Occurrences



MAP B-28. Distribution Relationships Between Molybdenum, Gold and Silver Occurrences



MAP B-29. Distribution Relationships Between Lead and Silver Occurrences



MAP B-30. Distribution Relationships Between Lead and Zinc Occurrences